ISR Application and Licensing Actions: Hydrogeology Lessons Learned

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ISR Regulation of Groundwater

NRC Objective: Protect the public health, safety and the environment

For groundwater , NRC regulates source and 11e(2) byproduct fluids at ISRs to ensure the licensee:

- **Characterizes, Sites and Designs ISR wellfields to ensure conditions are adequate to contain source and byproduct fluids within the wellfield to prevent contamination of surrounding groundwater.**
- **Operates ISR wellfields so that all source and byproduct fluids are contained within the wellfield and do not contaminate surrounding groundwater**
- **Monitors ISR wellfields so that any groundwater contamination outside wellfield from source and byproduct fluids is detected and corrected.**
- **Restores ISR wellfields to approved groundwater protection standards (GWPS) and to ensure no future contamination of surrounding groundwater by source and byproduct fluids.**
- **Treats and/or disposes of all waste source and byproduct fluids to ensure there is no contamination of groundwater in and surrounding the license area.**

ISR Application and Licensing Actions: Hydrogeology Lessons Learned

- Site Characterization
  - Geology
  - Existing Private Wells and CBM/oil/gas/injection wells
  - Aquifers /Aquitards
  - Aquifer Tests
  - Pre-op Water Quality
- Operations
  - Thin or discontinuous aquitards
  - Inward gradient (unconfined or confined aquifer)
  - Extraction rate limitations (unconfined or confined aquifer)
  - Monitoring well locations and excursion detection and correction
  - Free gas evolution / two phase flow / "gas lock"
  - Wellfield Hydrologic Test Data Packages
  - Analytical and Numerical Modeling
- Restoration
  - Baseline Water Quality/Restoration Standards
  - Pore Volumes/Flare
  - Wellfield sweep in unconfined aquifer
  - Waste water disposal capacity
  - Long term excursion restoration
  - Stability Monitoring Trend Analysis
- Emerging Issues
  - Consumptive water use
  - Interaction with nearby ISR operations
  - New lixiviants
  - ACLs
  - Geochemical Modeling
  - Natural attenuation

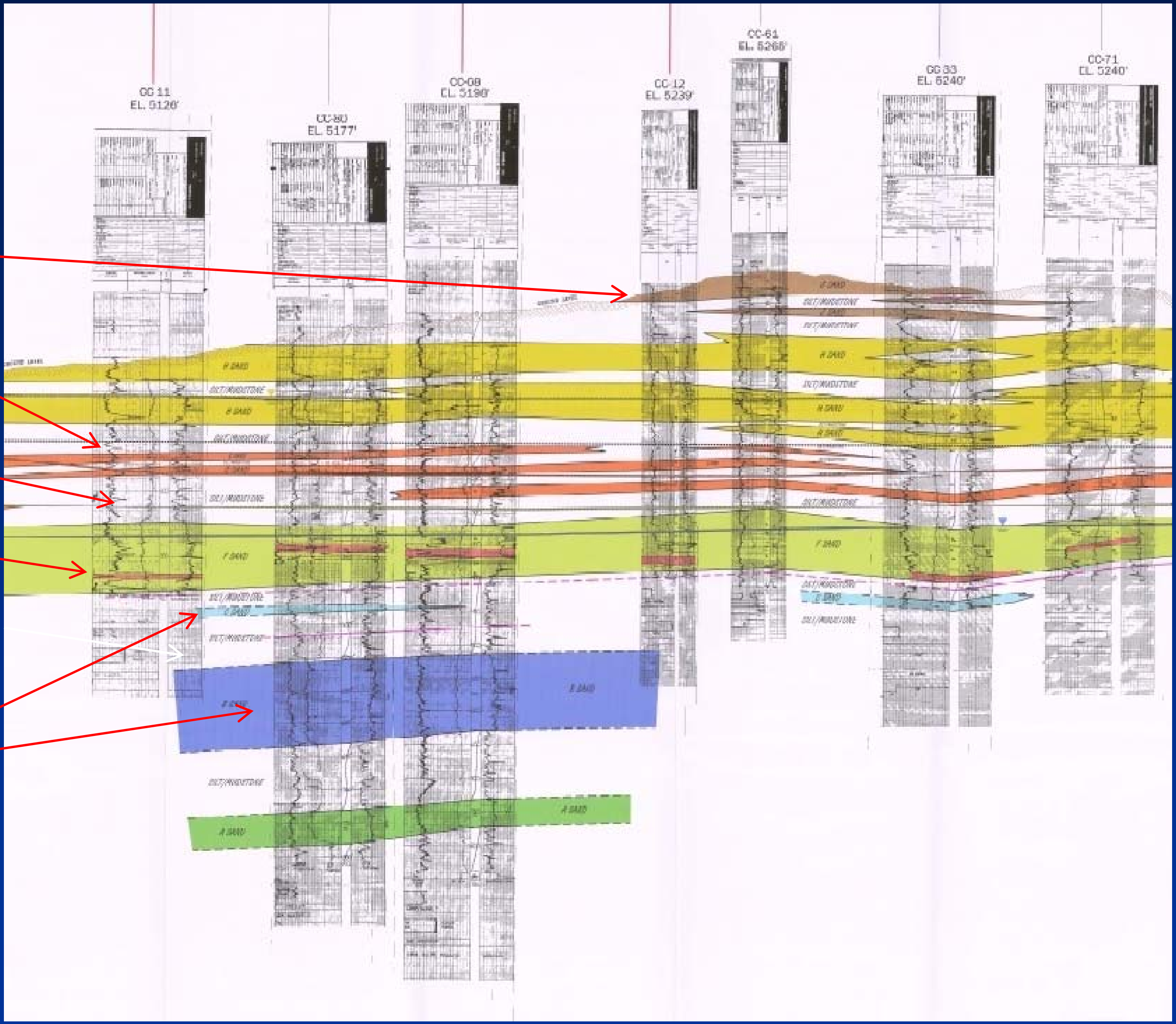
Lessons Learned: Site Characterization Geology

- Cross Sections (CSX)
  - Provide ground surface and features (drainages)
  - Label water levels of ore zone and other aquifers including surficial aquifer
  - Identify marker beds such coal seams/ ore deposits/CBM zones
  - Show continuity of layers
  - Provide CSX through well fields and features of concern
  - Address structural features: faults, outcrops, etc.

- Isopachs
  - Provide thickness of layers and continuity across license area
  - Identify thin spots, pinch outs, absence of layers

- Lithology
  - Provide description of lithology of license area formations
  - Correlate lithology between wireline logs, drillers logs, any continuous cores to justify layer picks and description
  - Use distinctive marker beds to justify layer picks: coals, clays, oxidized zones

Lessons Learned: Site Characterization
Provide Comprehensive Cross Sections



Ground Surface

Overlying Aquifers

Water Levels

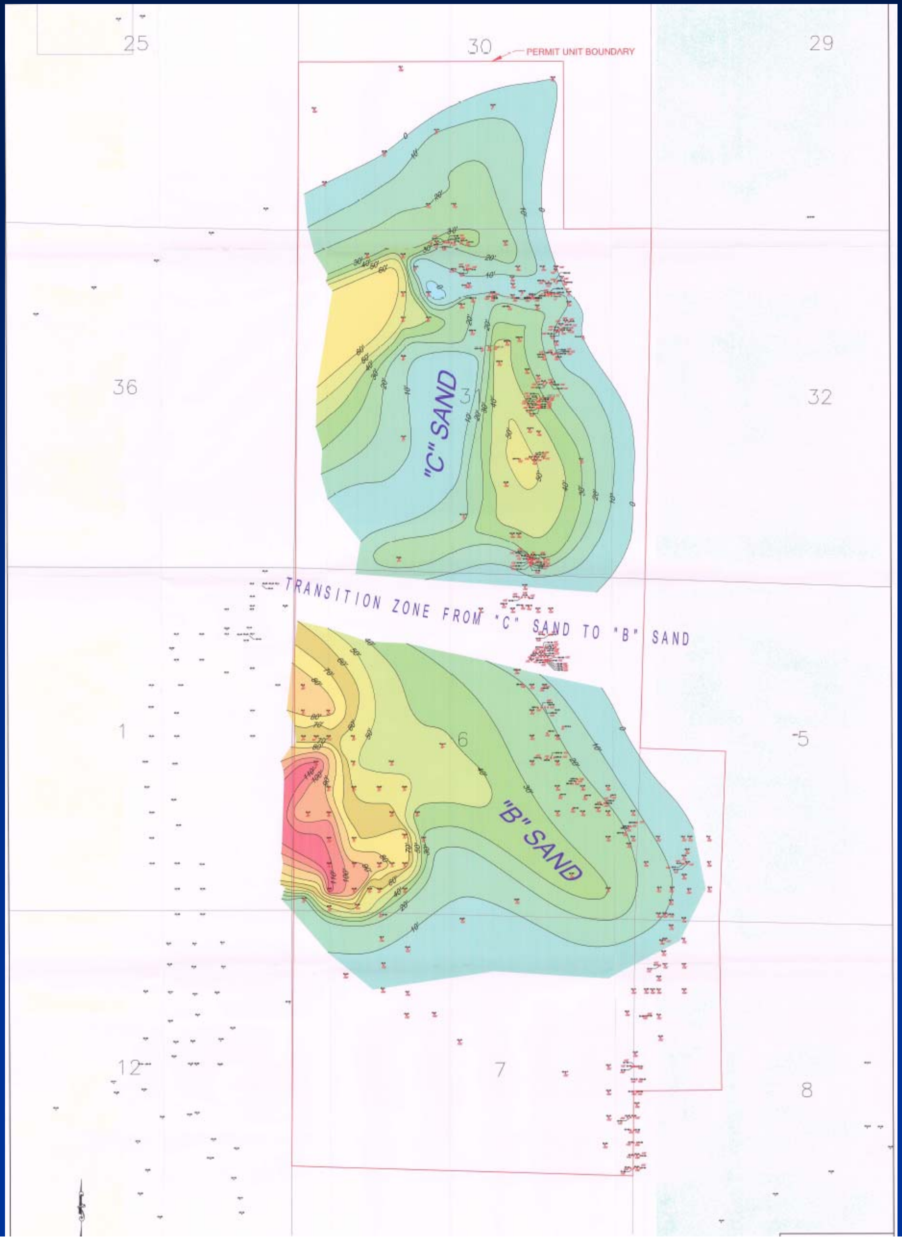
Ore locations

Underlying Aquifers

Lessons Learned: Site Characterization Provide Comprehensive Isopachs

Show variation in thickness of layers using boring/well picks

Show discontinuity of layers (case- 2 underlying aquifers)



Lessons Learned: Site Characterization
Provide Lithology from drillers logs on Well Completion Reports
http://seo.state.wy.us/wrdb/

Provides depths of layers and descriptions of drill cuttings

Enables correlation of layers between wells and to wireline logs.

U.W. 50985

10. PUMP TEST: Was a pump test made? Yes ☐ No ☒

If so, by whom ____ Address ____

Yield: ____ gal./min. with ____ foot drawdown after ____ hours.

Yield: ____ gal./min. with ____ foot drawdown after ____ hours.

11. FLOWING WELL (Owner is responsible for control of flowing well). Not flowing.

If well yields artesian flow, yield is ____ gal./min. Surface pressure is ____ lb./sq. inch, or ____ feet of water.

The flow is controlled by: valve ☐ cap ☐ plug ☐

Does well leak around casing? Yes ☐ No ☐

12. LOG OF WELL: Total depth drilled 196 feet.

Depth of completed well 196 feet. Diameter of well 5-1/2 inches.

Depth to first water bearing formation ____ feet.

Depth to principal water bearing formation Top ____ feet to Bottom ____ feet.

Ground Elevation, if known 5241.9'

From Feet	To Feet	Material Type, Texture, Color	REMARKS (Cementing, Shutoff, Packing, etc.)	Indicate Water Bearing Formation	Indicate Perforated Casing Location
0	60	Oxidized s.s.; yellow-orange v.f.-v.c. grnd.			
60	110	Fresh clay; blue-gray; V. silty & sandy			
110	120	Altered clay; reddish; v. silty & sandy; yellow			
120	195	Silty, oxidized; v.f.-v.c. grnd. (yellow-gray) s.s.			
195	196	Altered yellow-red; v.silty & sandy clay			

QUALITY OF WATER INFORMATION:

Was a chemical analysis made? Yes ☒ No ☐

If so, please include a copy of the analysis with this form.

If not, do you consider the water as: Good ☐ Acceptable ☐ Poor ☐ Unusable ☐

MICRO-FILMED NOV 26 '80

REMARKS

WELL NUMBER PN5-LMM3

ITEM 12

Well Log U.W. 54245

From Feet	To Feet	Material	Cemented Well Annulus	Water Bearing Interval	Screened Interval
0	80	org fn-cr snd	X	Lower	
80	110	bl arenaceous cly	X		
110	130	org fn-cr snd	X	X	
130	180	bl gry cly	X		
180	220	org fn-cr snd	X	X	
220	240	gry cly	X		
240	330	org-pnk fn-cr snd	X	X	
330	360	gry cly	X		
360	409	org-pnk fn-cr snd		X	X
409	416.5	gry cly			

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Lessons Learned: Site Characterization
Describe Existing Private Wells

- Describe Existing Private Wells (within 3 miles of a wellfield)
  - Locate and describe all domestic, stock, industrial (waterflood), miscellaneous, windmills
  - Provide available completion reports
  - Provide available water use permits
  - Provide map with locations of private wells (use completion report well name)
  - Provide table with all well descriptors (Coordinates for well locations)
  - Report screen location and assess which aquifer(s) are screened (use wireline logs, drillers logs to match lithology)
  - Determine current ownership, use and rate
  - Determine water quality if possible

- Describe Existing CBM/Oil/Gas/Injection Disposal Wells
  - Provide location, depth, screen, use, permits, target formations
  - Provide table of wells and map with these well locations

Lessons Learned : Site Characterization Provide Well Permit Reports for Existing Private Wells http://seo.state.wy.us/wrdb

Expected well use- monitoring, domestic, etc

Expected well depth and rate

Well Remarks

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Form U.W. 5

NOTE: Do not fold this form. Use type-writer or ball point pen.

STATE OF WYOMING

SCANNED SEP 29 2006

OFFICE OF THE STATE ENGINEER

APPLICATION FOR PERMIT TO APPROPRIATE GROUND WATER

Temporary Filing No. U.W. 6-6-19

PERMIT NO. U.W. 12299

NAME AND NUMBER OF WELL

UM 1575 2-33-42-75

WATER DIVISION NO. 2 DISTRICT 1

U.W. DISTRICT Campbell Co

SEE CURRENT ENDORSEMENT

1. Name of applicant(s) ~~Continental Oil Company - Uranium Exploration~~ Phone: 234-7311
2. Address of applicant(s) ~~200 North Wolcott, Casper, Wyoming~~ Zip: ~~82601~~
3. Name & address of agent to receive correspondence and notices Mr. Eugene A. Luckemeyer, Continental Oil Company, Uranium Exploration, 200 North Wolcott, Casper, Wyoming 82601
4. Use to which the water will be applied: Irrigation ☐ Municipal ☐ Industrial ☐ Commercial ☒ Domestic ☒ Stock Watering ☐ Other
5. Location of the well: Campbell County, NW ¼ SE ¼ of Sec. 33, T. 42 N., R. 75 W., or Lot ____, Block ____ of the ____ Subdivision (or Add'n) of ____, Sec. ____, T. ____ N., R. ____ W., of the 6th P.M. (or W.R.M.), Wyoming.
6. Estimated depth of the well is 420' feet.
7. MAXIMUM quantity of water to be developed and beneficially used: 20 gallons per minute. Note: If for domestic or stock use, this application will be processed for a maximum of 25 gallons per minute.
8. If for irrigation use,
   - ☐ Land will be irrigated from this well only.
   - ☐ Land is irrigated from existing water right(s) to be supplemented by this well. Describe existing water right(s) under REMARKS.
9. If for irrigation use, describe MAXIMUM acreage to be irrigated. Show number of acres to be irrigated in each 40-acre subdivision.

Township	Range	Sec.	NE¼				NW¼				SW¼				SE¼				TOTALS
			NE¼	NW¼	SW¼	SE¼	NE¼	NW¼	SW¼	SE¼	NE¼	NW¼	SW¼	SE¼	NE¼	NW¼	SW¼	SE¼	

REMARKS: Will use in temporary trailer camp and to fill existing reservoir for use in uranium exploration drilling. Plan to drill approximately 460', set casing, gravel pack and perforate a 70 foot water sand between 350' and 420'. Maximum anticipated work day use about 20,000 gallons per day. Duration of use not known at this time but will be for as long as drilling operations continue. Pump capacity in system will be approximately 16-20 gallons per minute.

Permit No. U.W. 12299

Book No. 66 Page No. 143

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Lessons Learned : Site Characterization
Provide Well Completion Reports for Existing Private Wells
http://seo.state.wy.us/wrdb

USGS 5-10-72
MICRO FILMED JUN 16'89
FILMED MAY 15'72
SCANNED SEP 29 2006

Form U.W. 6

NOTE: Do not fold this form. Use typewriter or print neatly with black ink.

IF WELL IS TO BE ABANDONED, SEE ITEM 15, PAGE 4

STATE OF WYOMING
OFFICE OF THE STATE ENGINEER
STATEMENT OF COMPLETION AND DESCRIPTION OF WELL
(For wells used only for stock or domestic purposes, use Form U.W. 7)

PERMIT NO. U.W. 12299 NAME OF WELL UM 1575 2-33-42-75

**SEE CURRENT ENDORSEMENT ON PERMIT*

1. NAME OF OWNER ~~Continental Oil Company~~
2. ADDRESS ~~200 North Wolcott, Casper, Wyoming~~ Zip Code 82601
3. USE OF WATER: Domestic ☐ Stock Watering ☐ Irrigation ☐ Municipal ☐ Industrial ☐ Commercial ☒
   Other
4. LOCATION OF WELL: NW ¼ SE ¼ of Section 33, T. 42 N., R. 75 W., of the 6th P.M. (or W.R.M.), Wyoming, being specifically (Bearing and Distance)
   or 3370 ft. North South and 2500 ft. East West from the NE corner of Section 33, T. 42 N., R. 75 W.
   (Strike out words not needed).
5. TYPE OF CONSTRUCTION: Drilled ☒ Rotary (Type of Rig) Dug ☐ Driven ☐ Jetted ☐
   Other
6. CONSTRUCTION: Total Depth 440 ft. Depth to Water Level 60 ft.
   a. Casing Schedule New ☐ Used ☒
      5 1/2" diameter from 0 ft. to 440 ft. Material Steel Gage 15 #/ft
      diameter from ft. to ft. Material Gage
      diameter from ft. to ft. Material Gage
   b. Perforations: Type of perforator used Perforated Before Purchase
      Size of perforations 1/16" inches by 3" inches.
      Number of perforations and depths where perforated:
      520 perforations from 375 ft. to 440 feet.
      perforations from ft. to feet.
   c. Was well screen installed? Yes ☐ No ☒
      Diameter: slot size: set from feet to feet.
      Diameter: slot size: set from feet to feet.
   d. Was well gravel packed? Yes ☒ No ☐ Size of gravel 1/4" gravel
   e. Was surface casing used Yes ☐ No ☒ Was it cemented in place? Yes ☐ No ☐
7. NAME & ADDRESS OF DRILLER A.O.K. Drilling Company, Casper, Wyoming
8. DATE OF COMPLETION OF WELL (including pump installation) December 29, 1971
9. PUMP INFORMATION: Manufacturer REDA Type Submergible
   Source of power Electric Powerline Horsepower 3HP Depth of Pump Setting 336 ft.
   Amount of Water Being Pumped < 10 gal/min Gallons Per Minute.

Permit No. U.W. 12299 Book No. 66 Page No. 143

Completed well type-monitoring, domestic, etc

Completed well depth, casing and screen description

Completed well rate and pump installation

Applicant/ licensee should:

1. **Verify well exists and ownership**
2. **Verify well use and rate**
3. **Verify aquifer(s)**
4. **Test water quality if possible**

Lessons Learned: Site Characterization Surface Water

- **Describe all drainages - estimate peak flood values and velocity at recurrence intervals, outline flood prone regions**
- **Describe surface water reservoirs, ponds, etc.**
- **Provide information on CBM discharges and impoundments- construction, location, permits, dates of operation, cumulative discharge, any agreements with CBM operators, future CBM operations**
- **Get surface water samples if possible to determine seasonal water quality or impacts from CBM discharge, etc.**

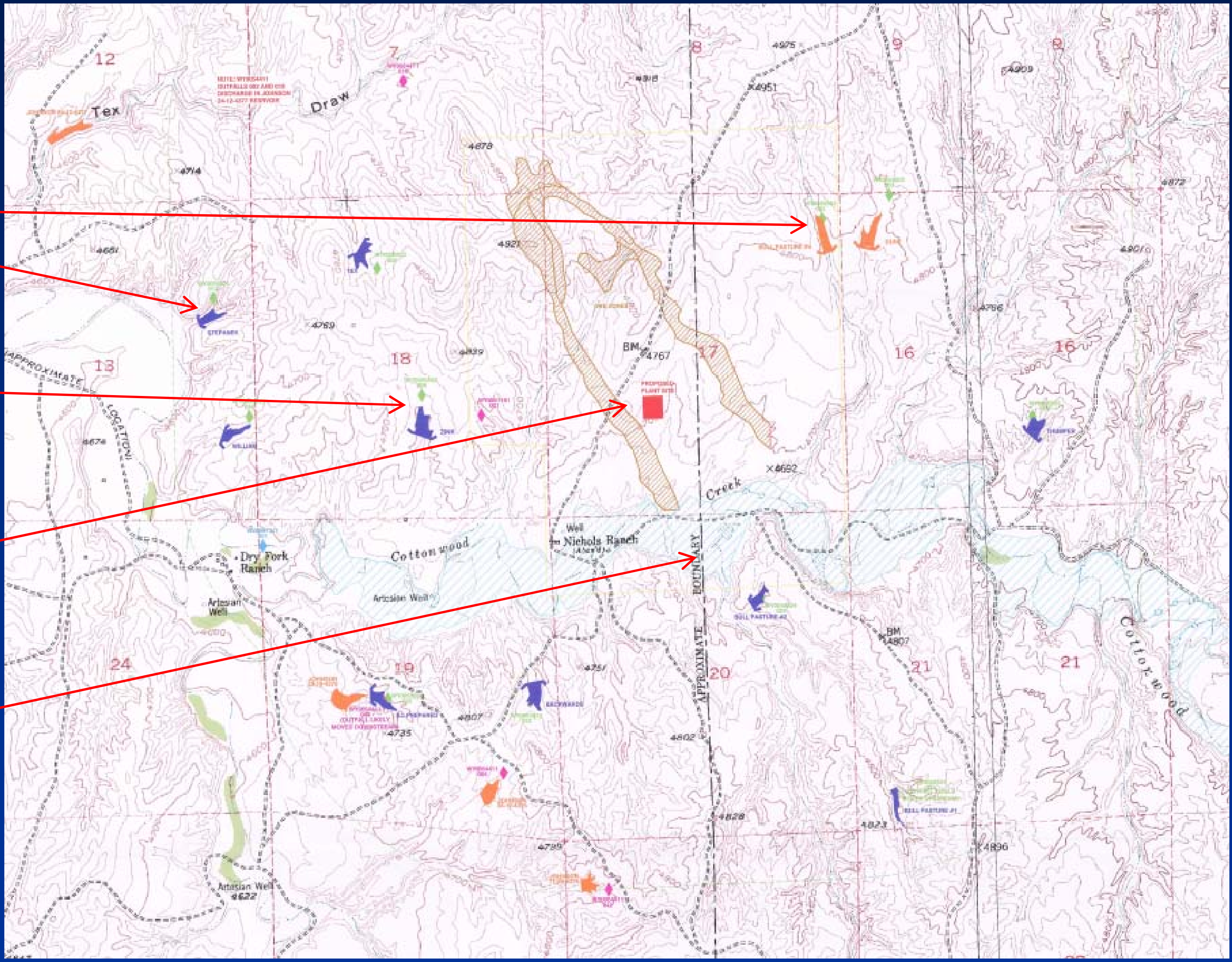
Lessons Learned: Site Characterization Describe Surface Water Drainages, Reservoirs, CBM impoundments, flood zones

CBM impoundments

CBM permits

Ore body

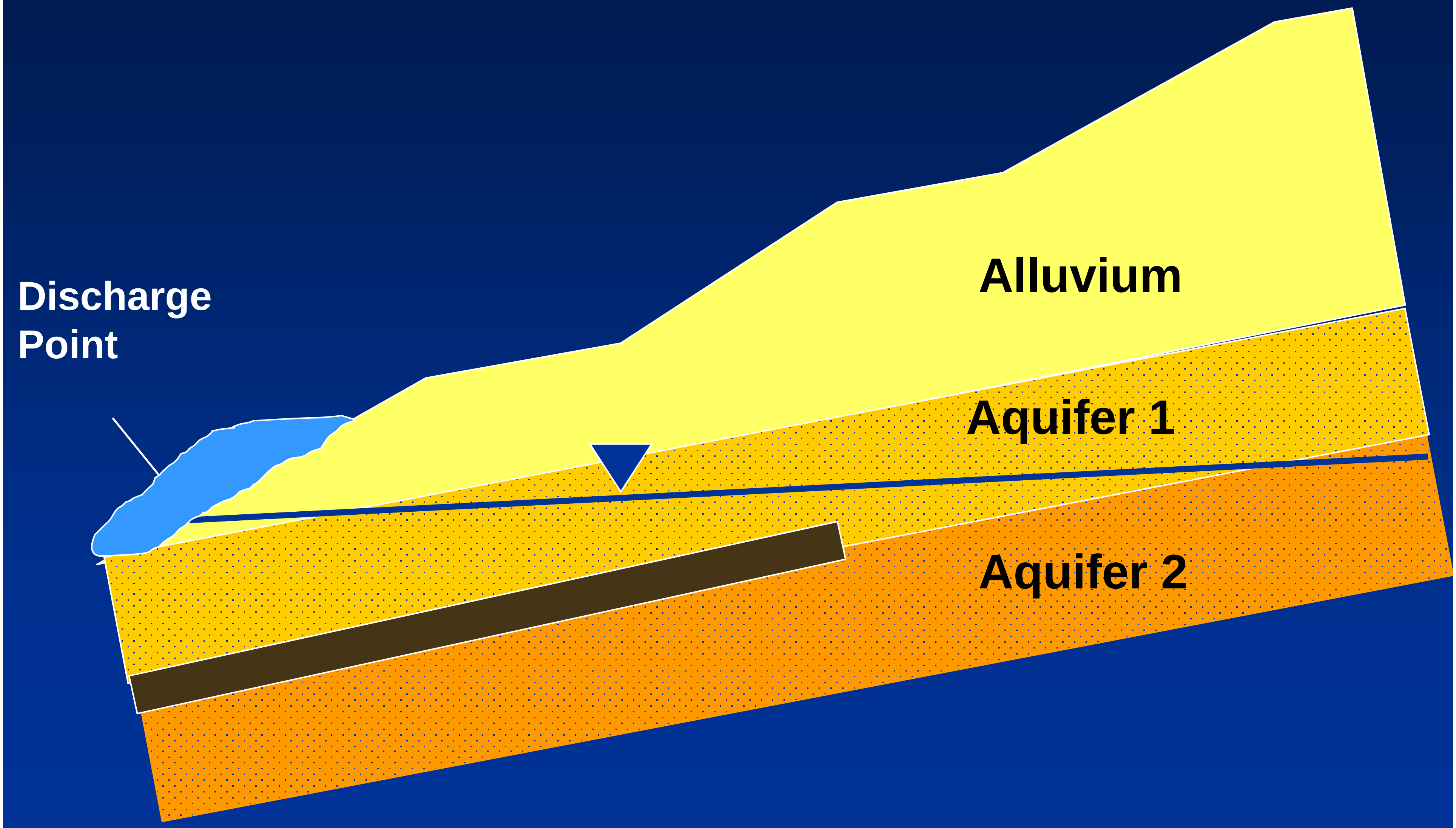
Area of 25 year Flood



Lessons Learned: Site Characterization Surficial Aquifer

- Indicate which formations act as surficial aquifer
- Show recharge /discharge areas
- Provide depth to groundwater contours
- Evaluate connection to surface water
- Provide info on private wells- location/rates/use
- Show location of CBM infiltration impoundments
- Determine groundwater flow magnitude and direction

Lessons Learned : Site Characterization Identify which formation(s) act as surficial aquifer



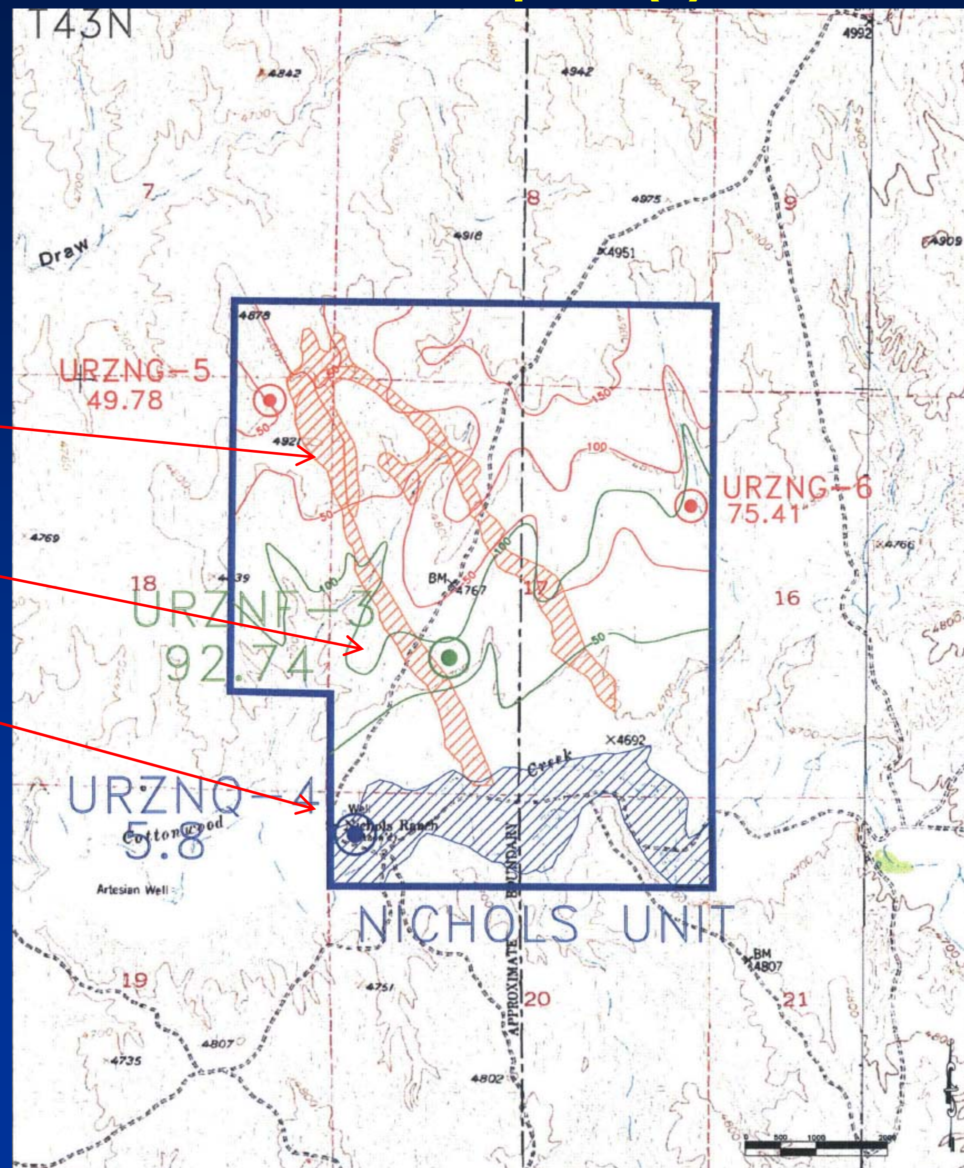
Lessons Learned: Site Characterization Provide contours of depth to water in surficial aquifer(s)

Example: Three formation(s) act as surficial aquifer

G Aquifer

F Aquifer

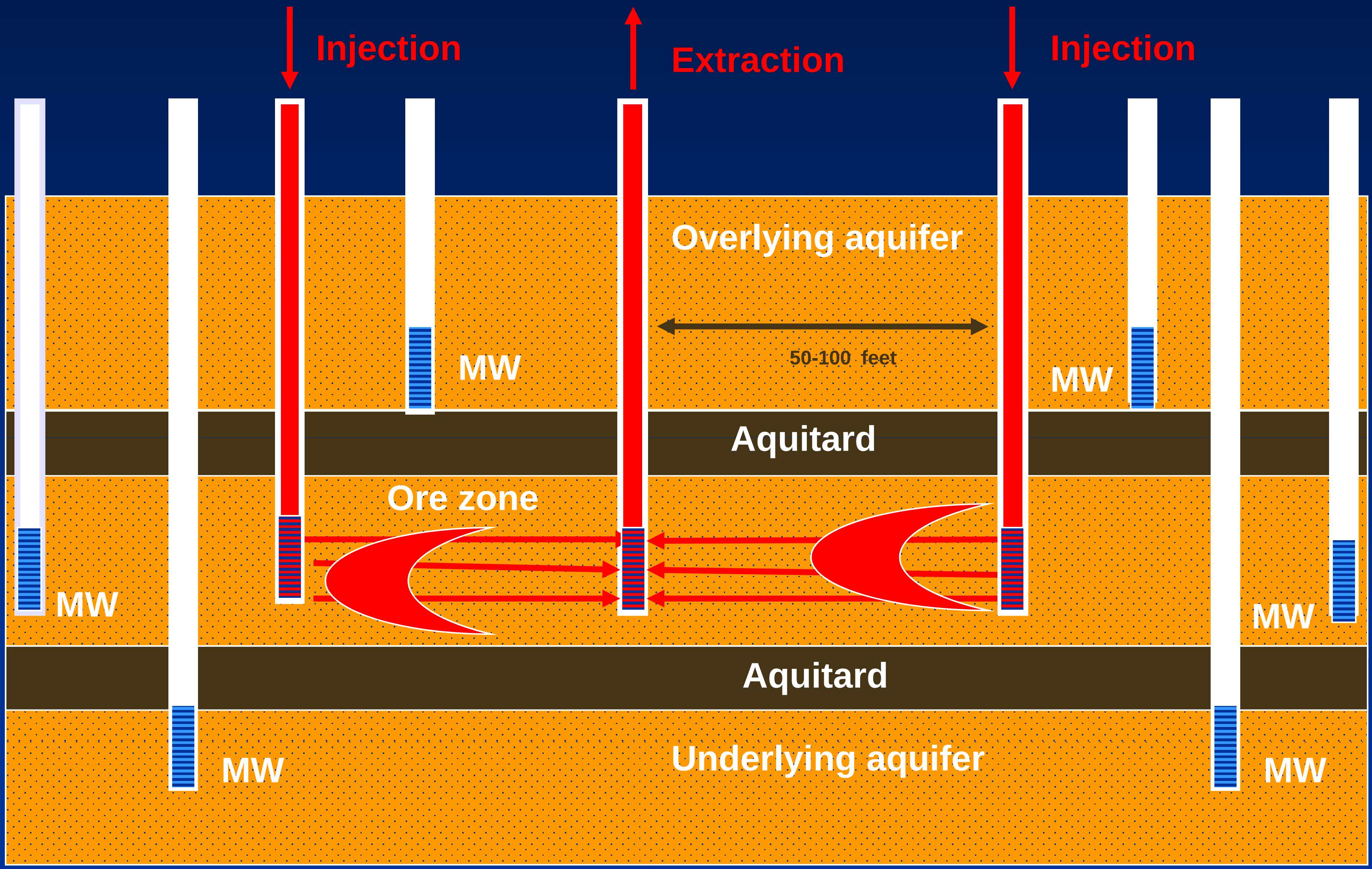
Alluvium Aquifer



Evaluate potential for GW discharge to surface water .

Example-connection of alluvium aquifer to creek drainage in south (WL= 5.8 ft bgs)

Lessons Learned: Site Characterization
Ore Zone, Overlying and Underlying Aquifer



Lessons Learned: Site Characterization Describe Ore Zone and Overlying/Underlying Aquifers

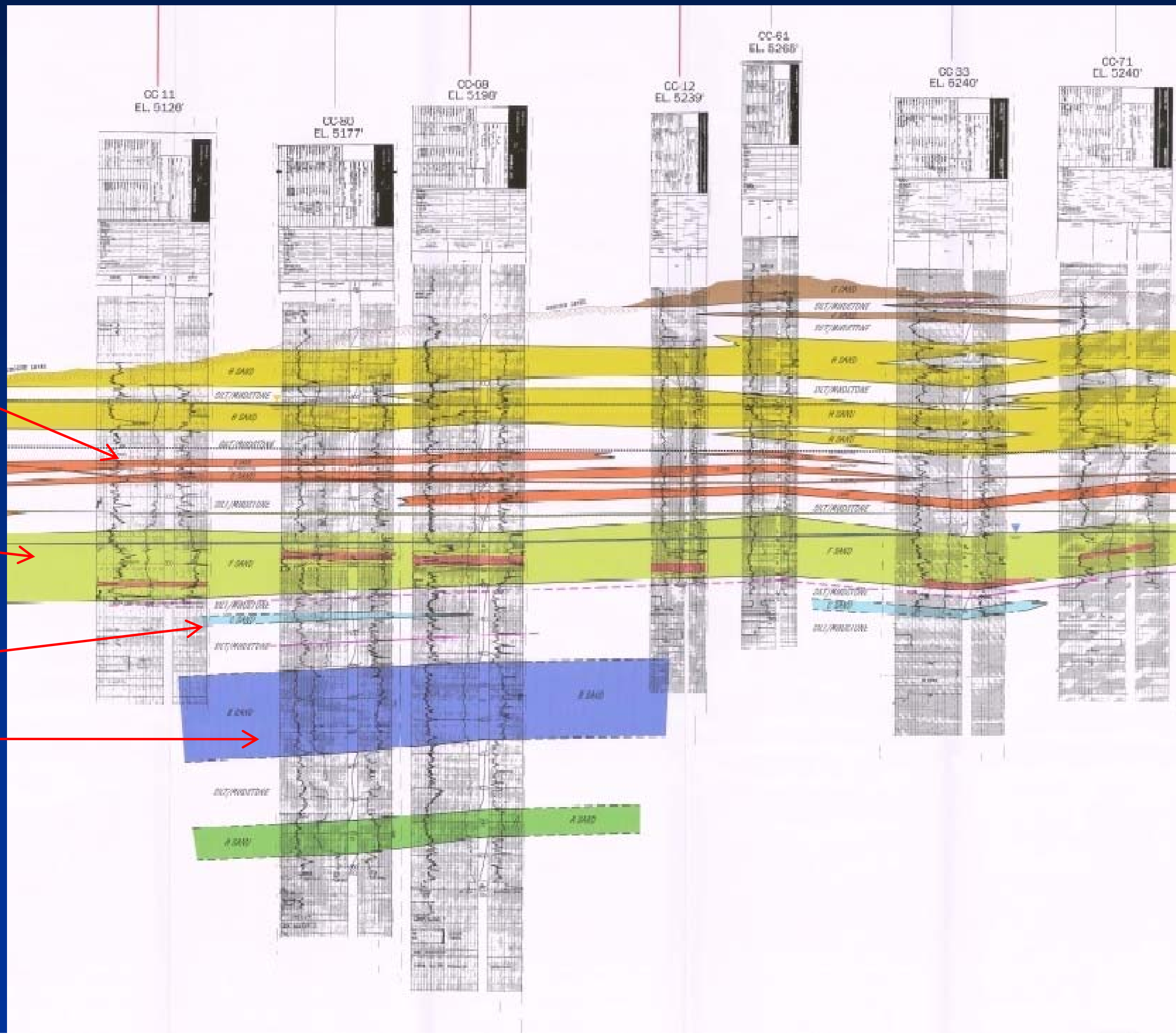
- Identify which formations act as overlying and underlying aquifers
- Identify aquitard(s) which are overlying and underlying to ore zone.
- Describe locations where aquitards are leaky, thin or discontinuous. Provide vertical gradients across aquitards.
- Provide maps of water levels/potentiometric surface in overlying and underlying aquifers (use sufficient number of points to define maps, don't extrapolate)
- Estimate ground water flow magnitude and direction in each aquifer
- Provide historical and present water level hydrographs- address any water level anomalies

Lessons Learned: Site Characterization Provide Cross Section with Overlying/Ore Zone/Underlying Aquifers

Overlying Aquifer (s)

Ore Zone Aquifer

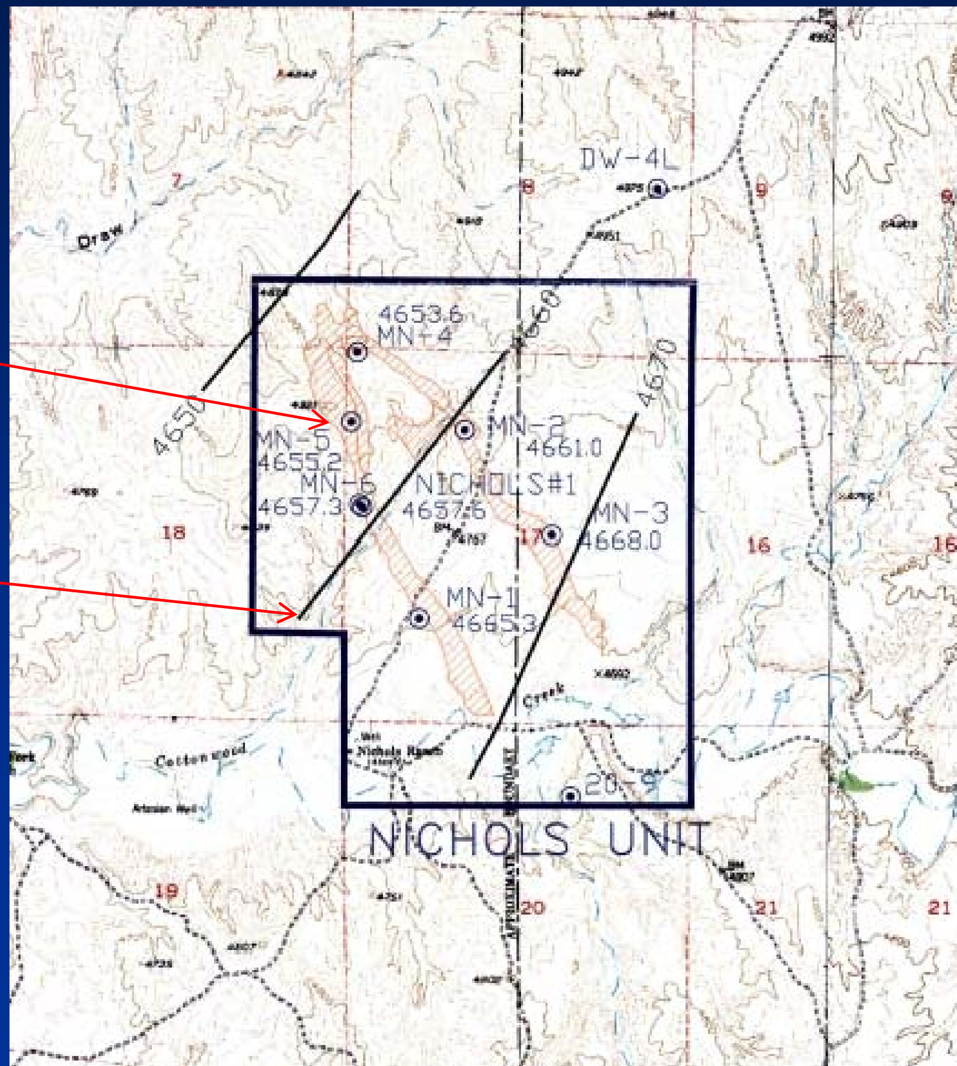
Underlying Aquifer (s)



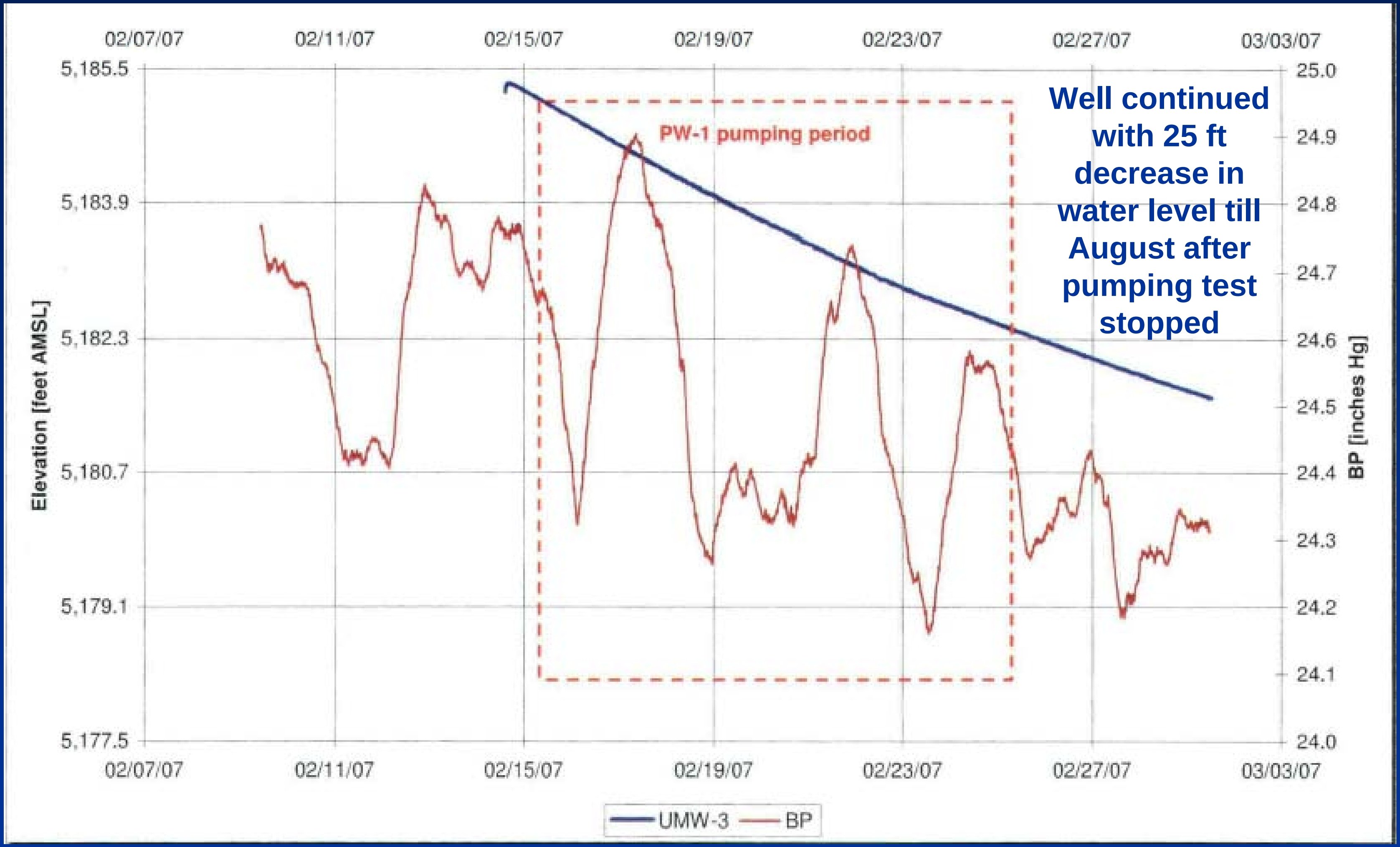
Lessons Learned: Site Characterization
Provide Accurate Aquifer
Potentiometric Surface Maps

Provide sufficient number of wells and coverage

Do not extrapolate past measured points



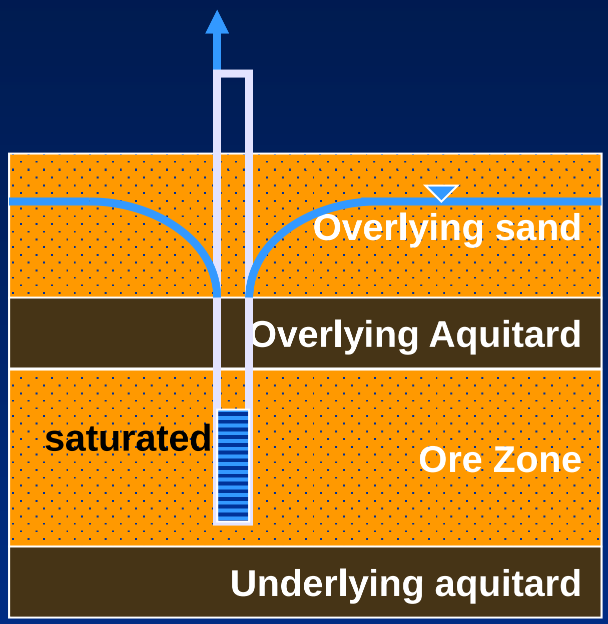
Lessons Learned: Site Characterization
Describe and investigate water level anomalies in wells

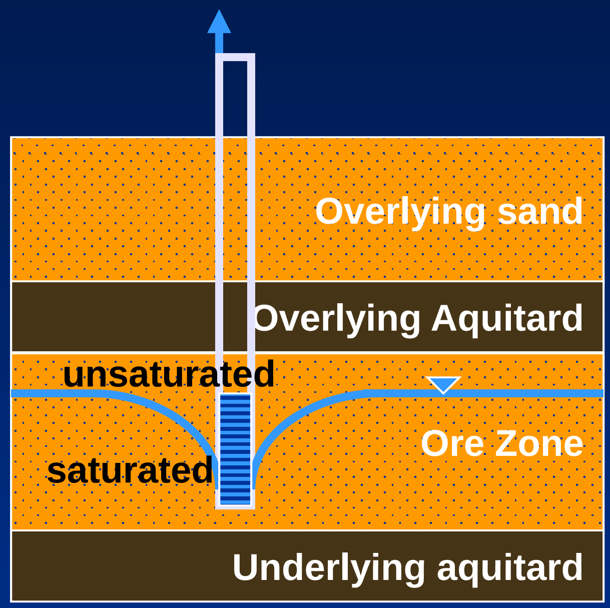


Lessons Learned: Site Characterization Ore Zone Aquifer Tests

- Design
  - Use aquifer appropriate test- unconfined/confined
  - Use appropriate location, number of observation wells
  - Use appropriate rates, length of time
  - Use completion reports for wells, screen location
  - Use observations wells in overlying/underlying aquifers
  - Use appropriate pumping tests to assess overlying/underlying aquifer if aquitards thin or discontinuous
- Analysis
  - Use aquifer appropriate analysis (unconfined/confined/leaky, etc.)
  - Perform analysis of boundaries, faults
  - Perform analysis of leaky aquitards
  - Use groundwater flow modeling to characterize flow behavior in special conditions
- Variations (for special circumstances)
  - Step rate tests- limiting extraction rate in unconfined aquifers
  - Five spot pattern tests- unconfined aquifers
  - Line drive pattern tests- unconfined aquifers

Lessons Learned: Site Characterization
Appropriate aquifer tests
Drawdown in confined vs. unconfined aquifer





Confined drawdown equation

$$s = \frac{264Q}{T} \log \frac{0.3Tt}{r^2 S}$$

S=coefficient of storage

Unconfined drawdown equation

$$s = \frac{264Q}{T} \log \frac{0.3Tt}{r^2 S_y}$$

S= Sy= Specific Yield

s=drawdown (ft) Q=pumping rate (gpm) T =transmissivity (gpd/ft)

t=time (days) r=distance of observation from pumping well (ft)

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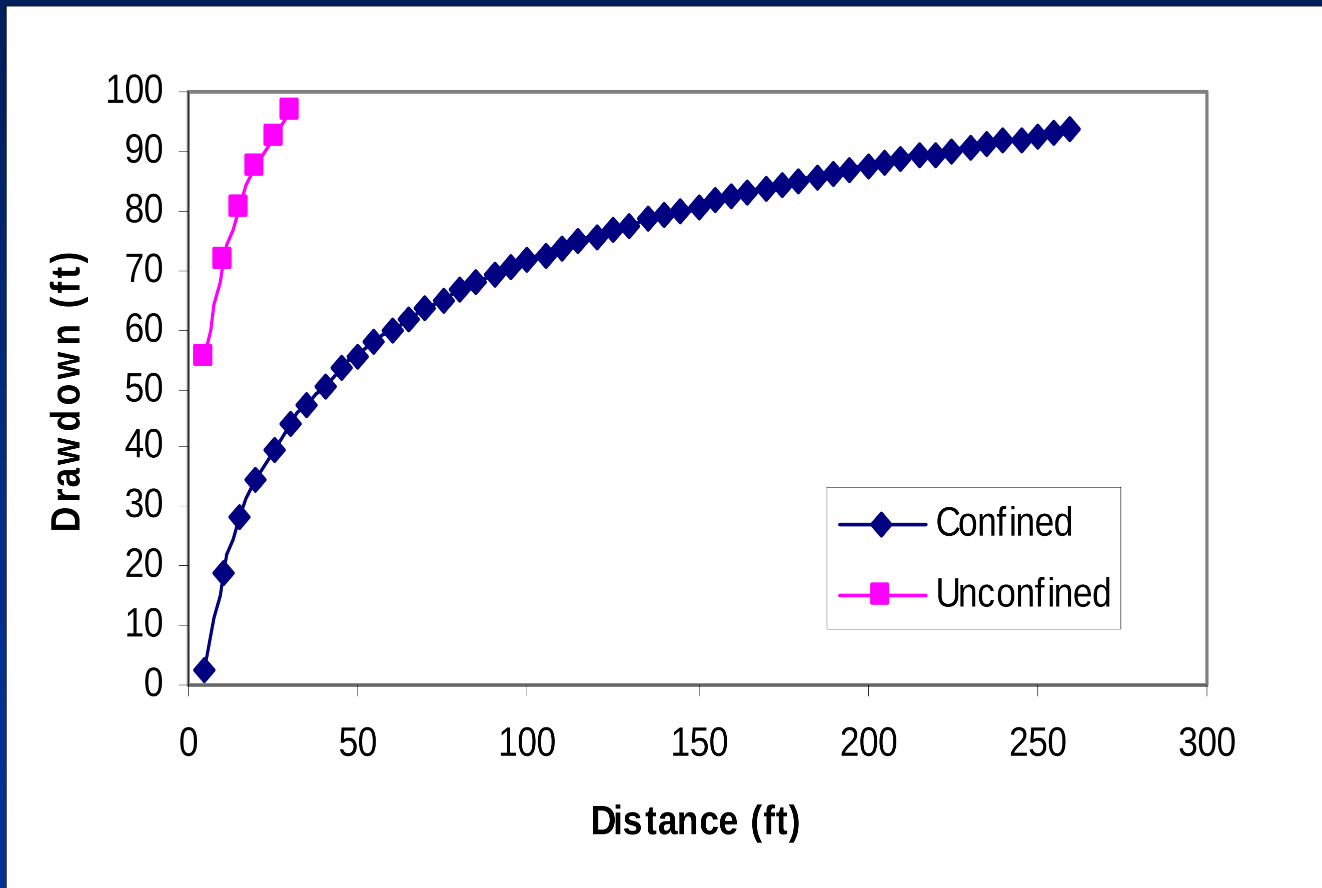
Site Characterization: Theoretical drawdown in confined vs. unconfined aquifer

Example: Well Q=20 gpm, T=200 gpd/ft, t =1 day, S=.0005 (confined), Sy=.05 (unconfined)



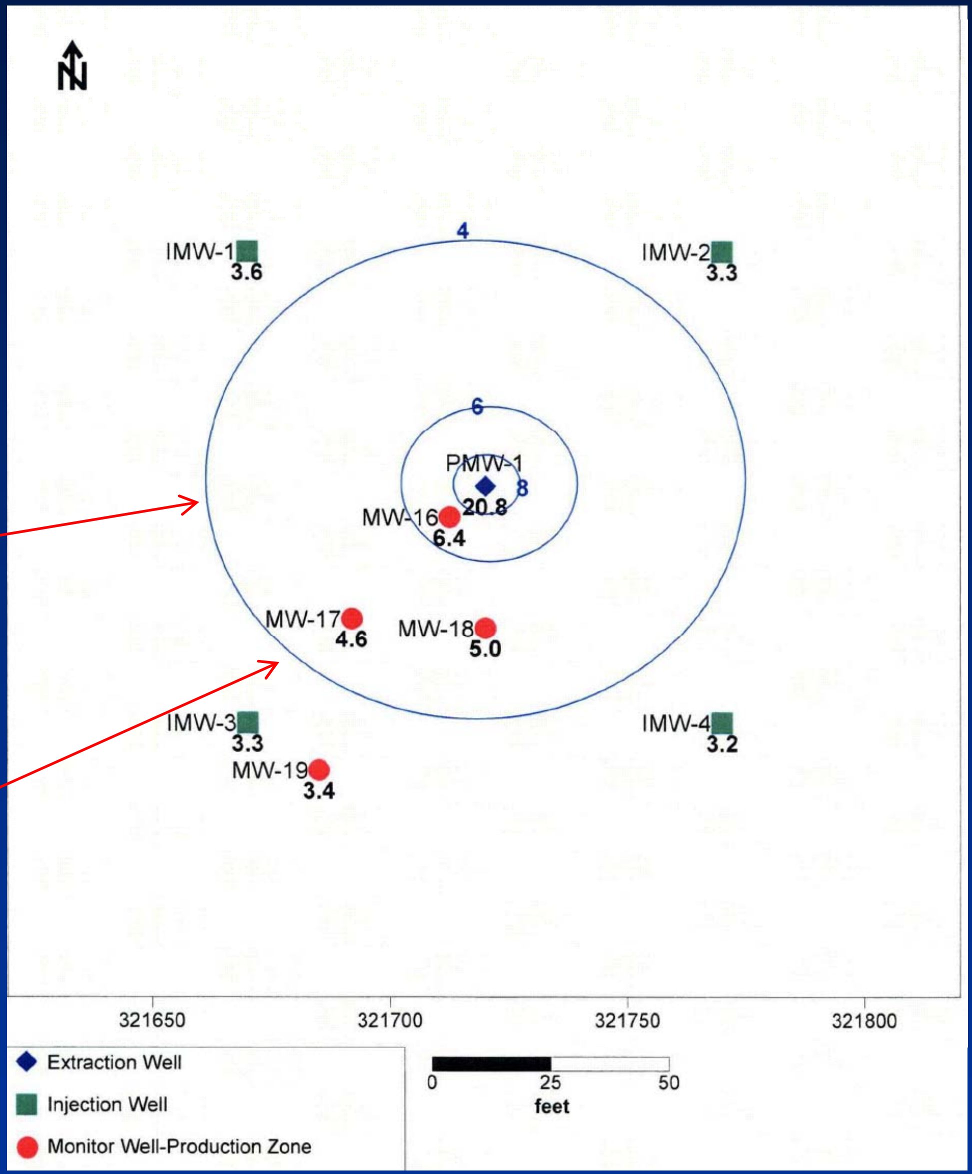
Observation wells must be closer to pumping well in the unconfined aquifer to pick up drawdown, underlying and overlying wells must also be close to pumping well

Site Characterization: Evaluate field aquifer tests, example drawdown in unconfined aquifer

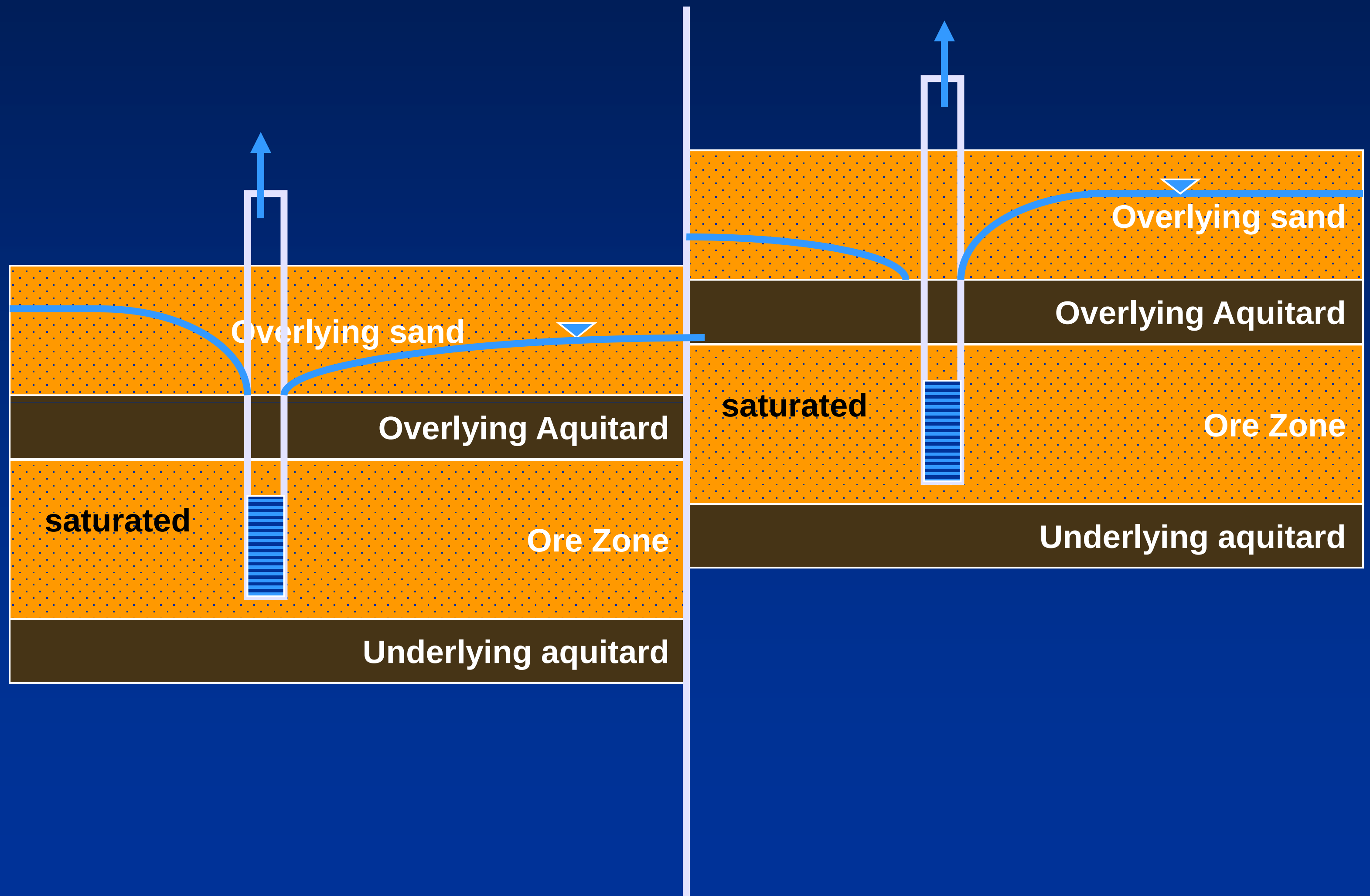
Example: Field aquifer test in unconfined aquifer

Small region (< 100 ft) of dewatered drawdown in an unconfined aquifer

Steep drawdown surface (3.3 ft to 20 ft over 75 ft)



Lessons Learned : Site Characterization
Provide appropriate aquifer tests for drawdown near a fault

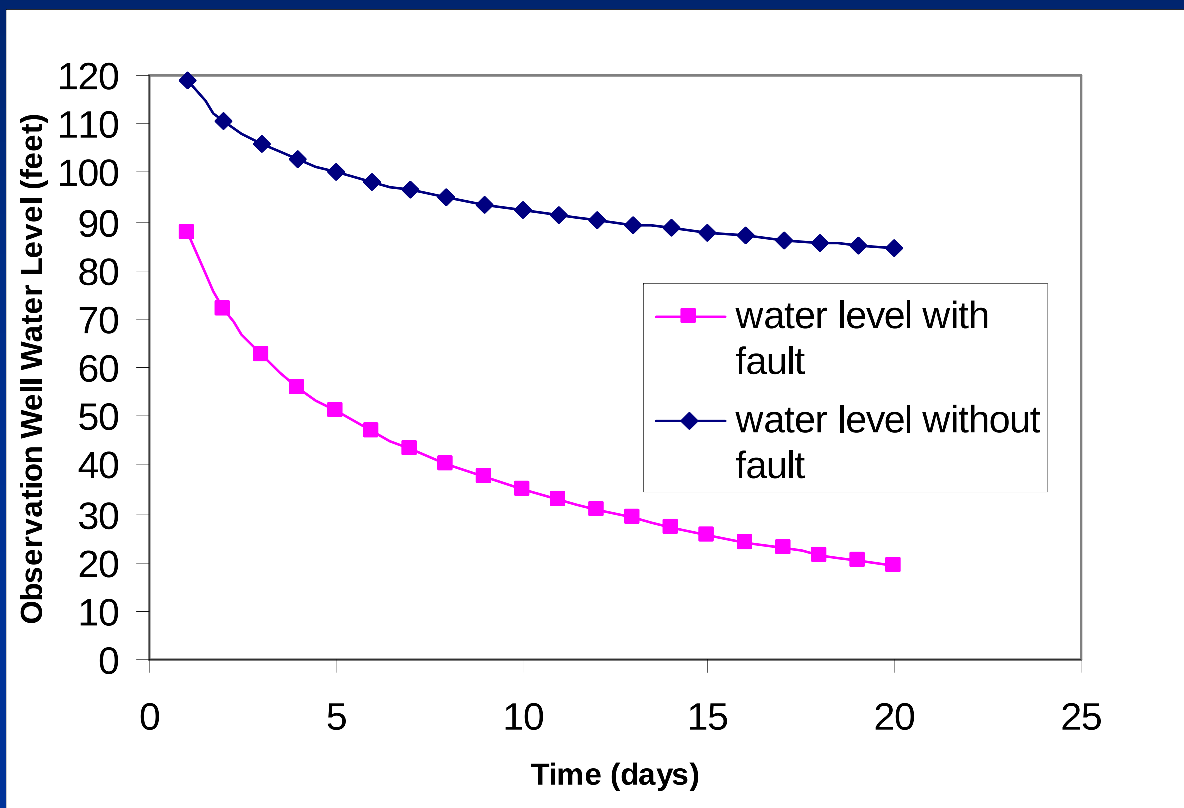


Site Characterization: Theoretical drawdown near a sealing fault

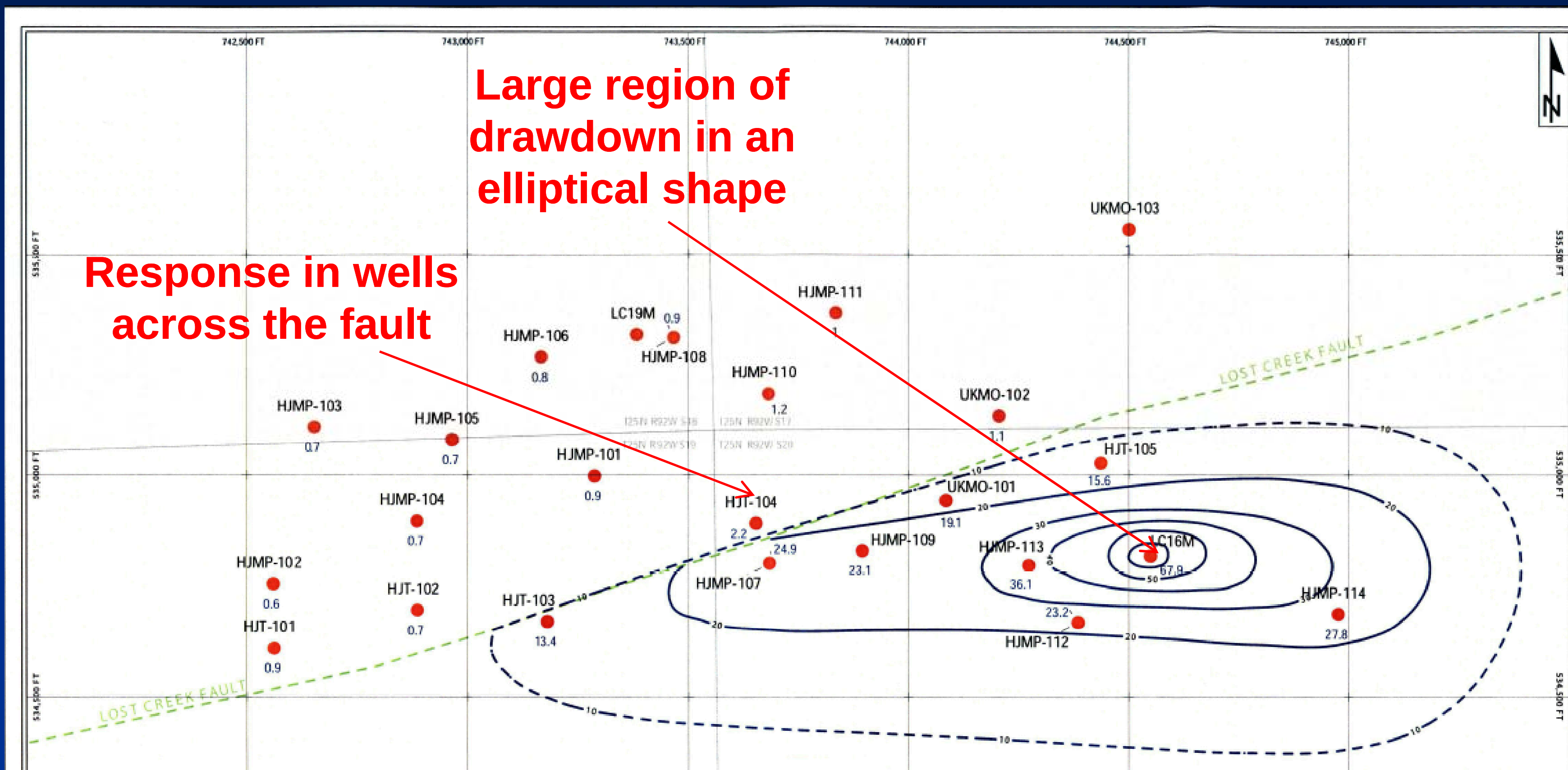
Example: Q=20 gpm, T=200 gpd/ft, t=1 day at observation well 10 ft from real well and 90 ft from image well (r_r=10 ft, r_i=90ft)

$$s_T = \frac{264(20gpm)}{200gpd/ft}\log\frac{0.3(200gpd/ft)(1day)}{(90ft)^2(.0005)} + \frac{264(200gpm)}{200gpd/ft}\log\frac{0.3(200gpd/ft)(1day)}{(10ft)^2(.0005)}$$

Image well drawdown   Real well drawdown



Site Characterization: Evaluate field aquifer tests Example drawdown in confined aquifer near a partially sealing fault

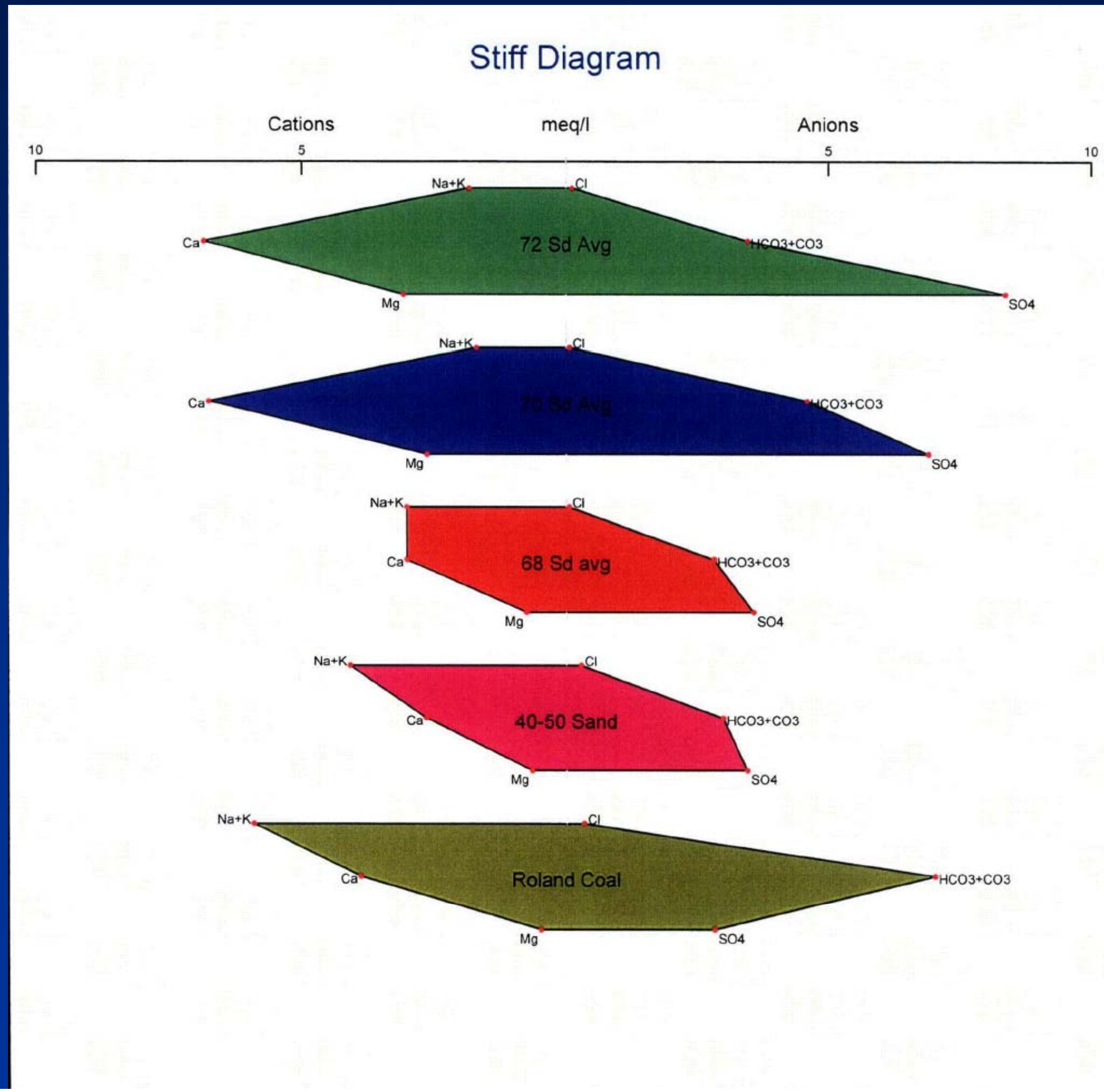


Lessons Learned: Site Characterization Provide Pre-op (Application) Groundwater Quality

- Collect samples from all wells in all potentially impacted aquifers across license area
  - Surficial Aquifer (s) - 4 quarters
  - Production Aquifer (s) - 4 quarters
  - Overlying Aquifers (s) - 4 quarters
  - Underlying Aquifer(s) – 4 quarters
- Provide samples from private wells within 2 km of wellfield
- Measure NUREG 1569 Table 2.7.3-1 parameters in each sample
- Provide available historical water quality from wells (e.g. , prior mine application, prior ISR pilot operations)
- Evaluate seasonal trends
- Evaluate variations in water quality which could be a consequence of historical CBM or other operations (ISR pilots, oil/gas, etc)
- Provide Piper and Stiff diagrams of water quality in all aquifers(very helpful to visualize type of water)

Site Characterization: Describe pre-op water quality

Example:
Stiff diagram to visualize type of water in wellfield aquifers and CBM zone



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Lessons Learned: ISR Operation

- **Evaluate interaction with overlying and underlying aquifers when shales thin or discontinuous or faults present**
- **Demonstrate ability to maintain inward gradient at all times**
  - **Consider aquifer conditions: unconfined vs. confined**
  - **Consider patterns: five spot vs. line drive**
- **Determine any extraction rate limitations (unconfined/ confined to unconfined)**
- **Demonstrate ability to detect and correct excursions in all settings**
- **Describe how to detect and correct for free gas evolution / two phase flow in aquifer leading to gas lock and problems with wellfield infrastructure (pipes, pumps, flow and pressure gauges).**
- **Supporting lines of evidence for conclusions**
  - **Field tests**
  - **Analytical/ Numerical groundwater modeling**

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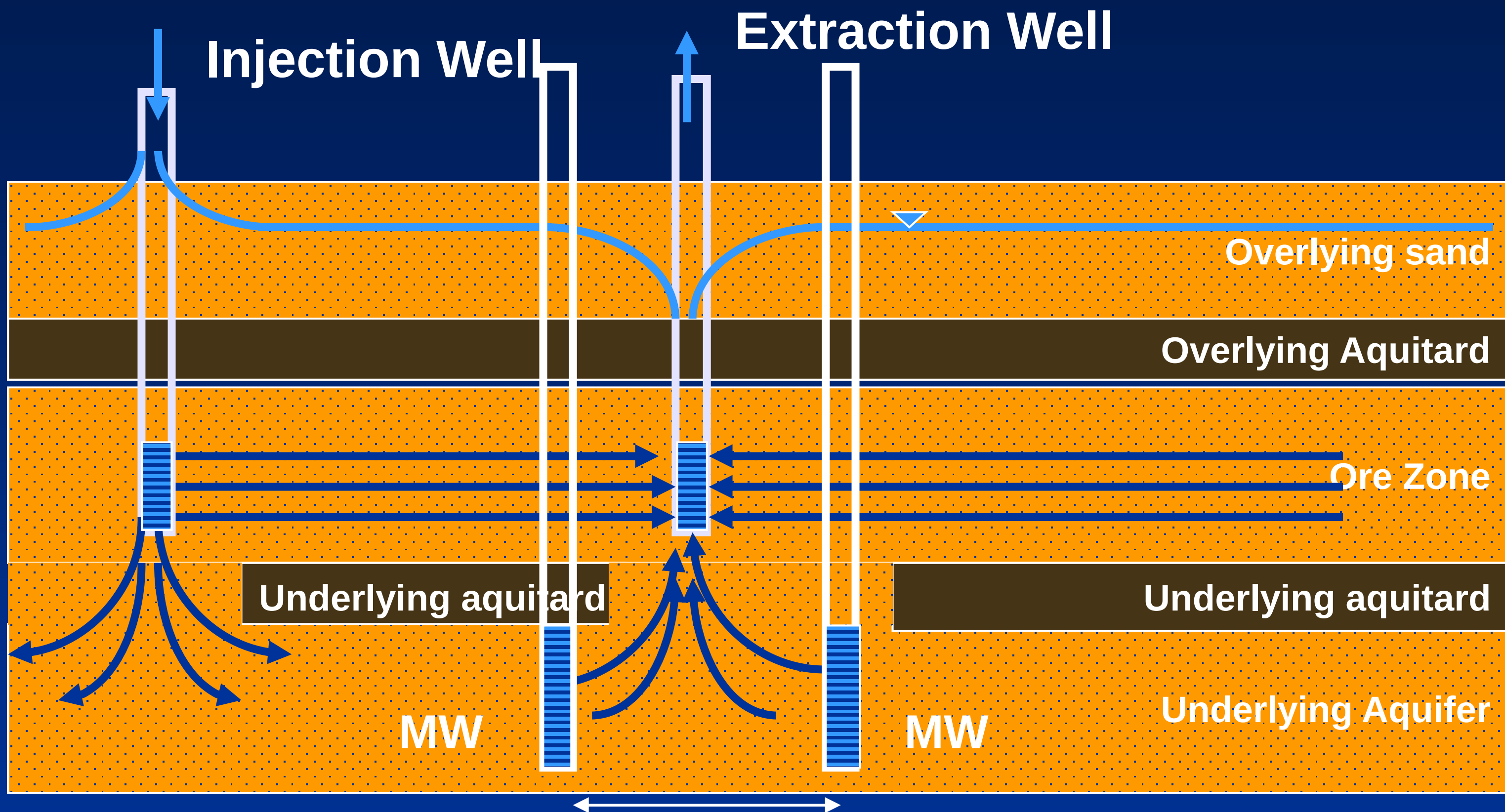
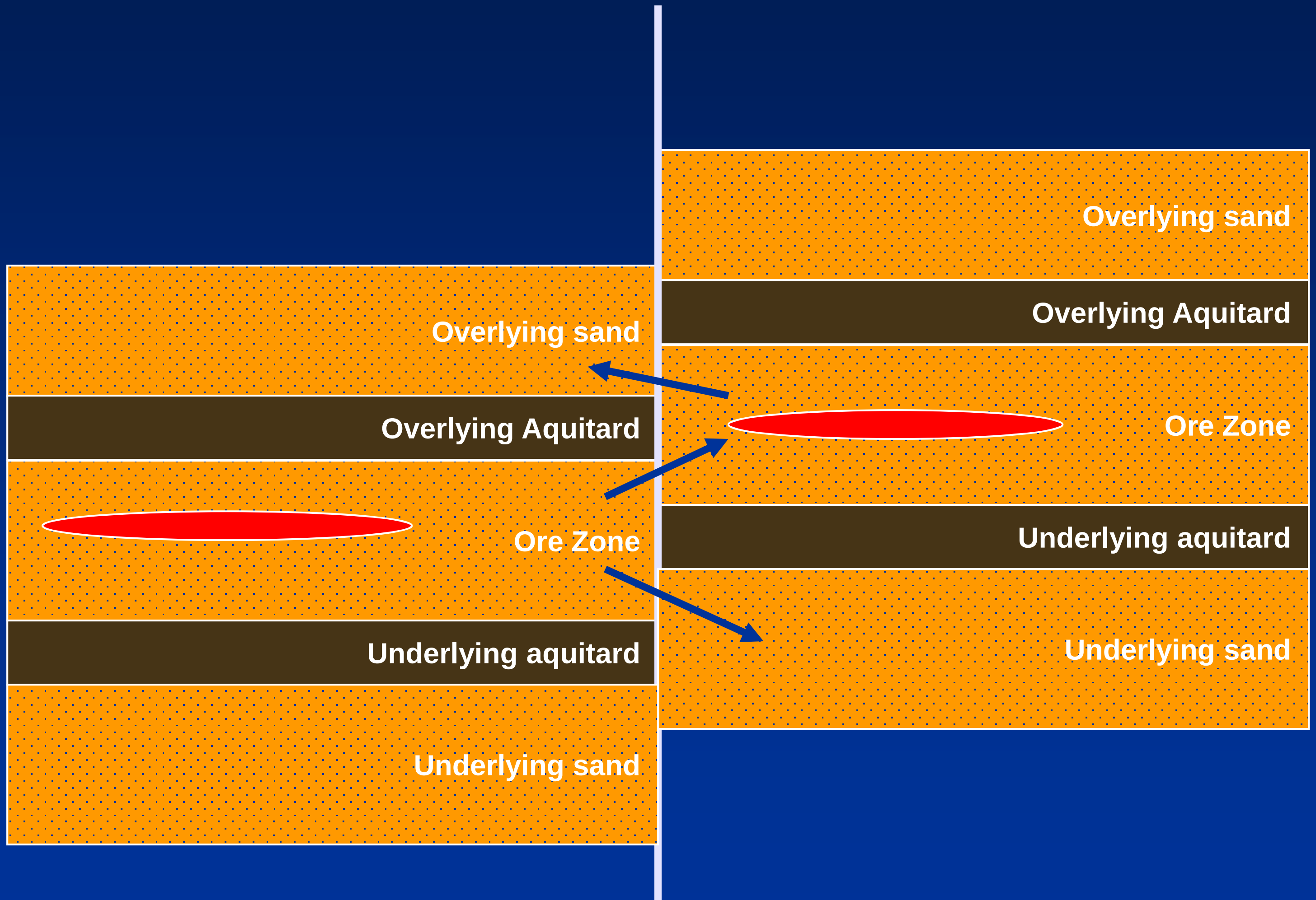
Lessons Learned: ISR operation
Evaluate interaction of ore zone with underlying or overlying aquifers across thin or discontinuous confining layers



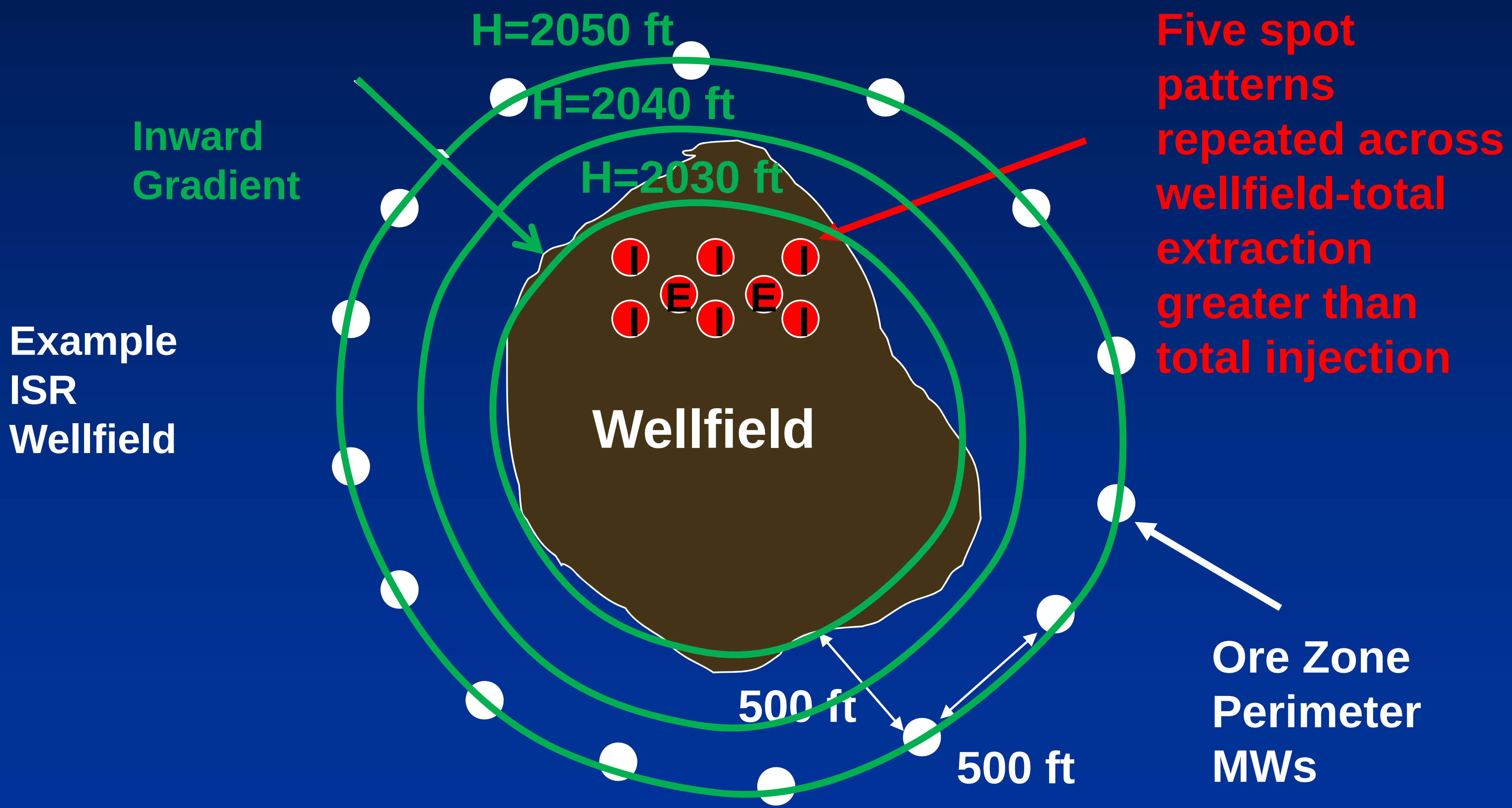
Pumping tests may show interaction with underlying aquifer, or little to no interaction if substantial difference in hydrogeologic characteristics

Question to answer: Is confinement really present or should aquifers be combined as one production zone?

Lessons Learned: ISR operation Evaluate interaction of ore zone with offset underlying or overlying aquifers across faults



Lessons Learned: ISR Operation
Demonstrate inward gradient to prevent excursions



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ISR Operation : Inward gradient Confined vs. Unconfined Aquifer

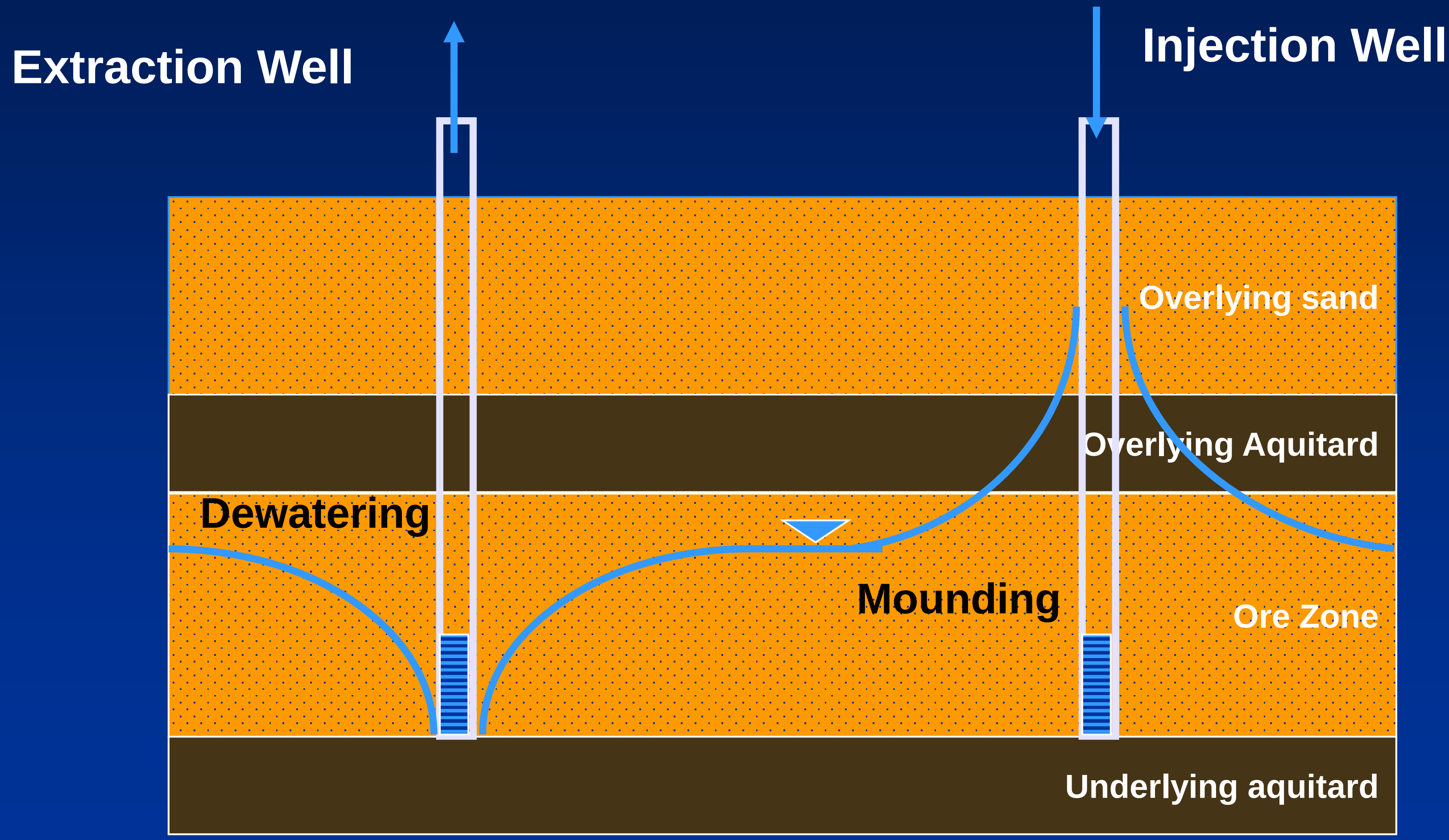
Confined aquifer:

- Water to meet pumping rate is released by compression of sediments and expansion of water so much larger volume of aquifer is impacted.
- Produces large "pressure cone of depression" which typically ensures large inward gradient during operations to prevent fluid movement from wellfield.

Unconfined aquifer:

- Water to meet pumping rate is released mainly by dewatering so much smaller volume of aquifer is impacted.
- Extraction wells produce smaller "dewatered cones of depression," and injection wells create ground water mounds.
- This flow pattern with bleed may not create inward gradient necessary to prevent fluid movement from wellfield.

ISR Operation: Inward Gradient
Unconfined aquifer creates localized dewatering and mounding



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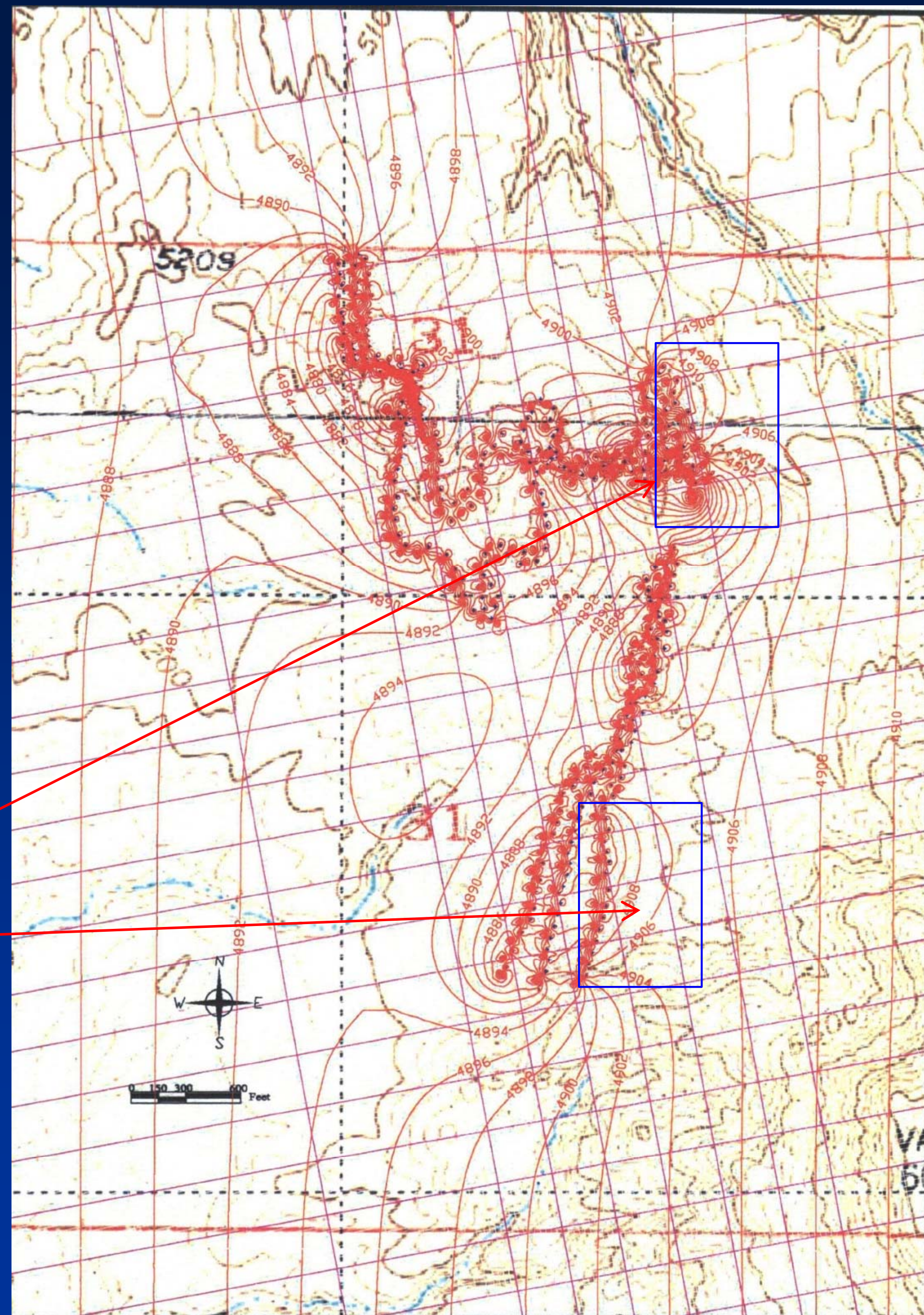
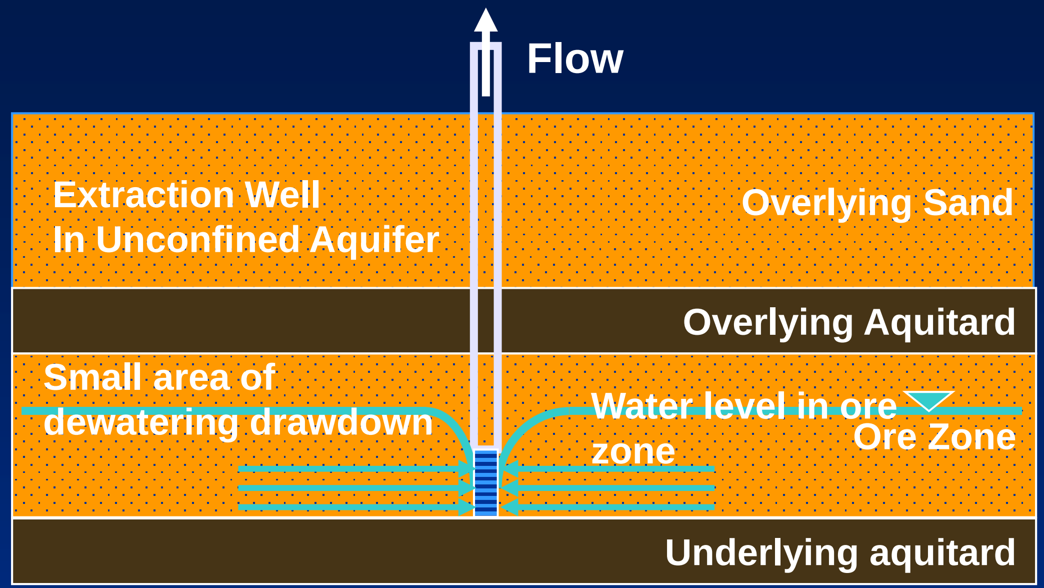
Example:
ISR Wellfield with line drive pattern in unconfined aquifer- injection wells upgradient (east side)

Issue: Outward gradients are developed from mounding near injection wells on upgradient side after one year of proposed production operations

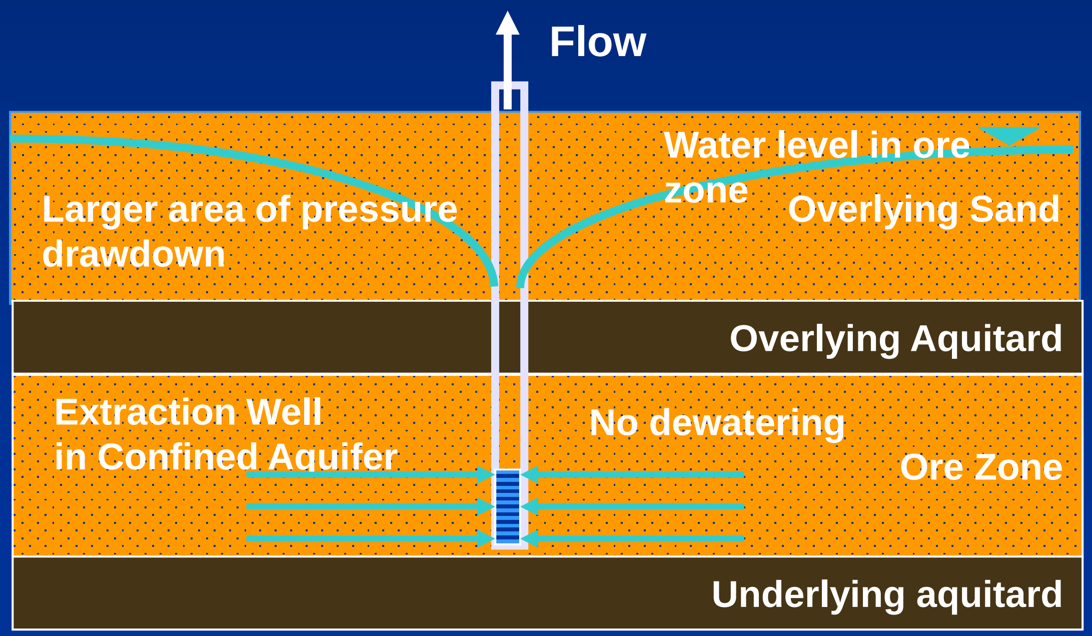


Lessons Learned : ISR Operation
Evaluate dewatering in unconfined aquifer

Unconfined aquifer:
Dewaters near well if rates exceed some limit



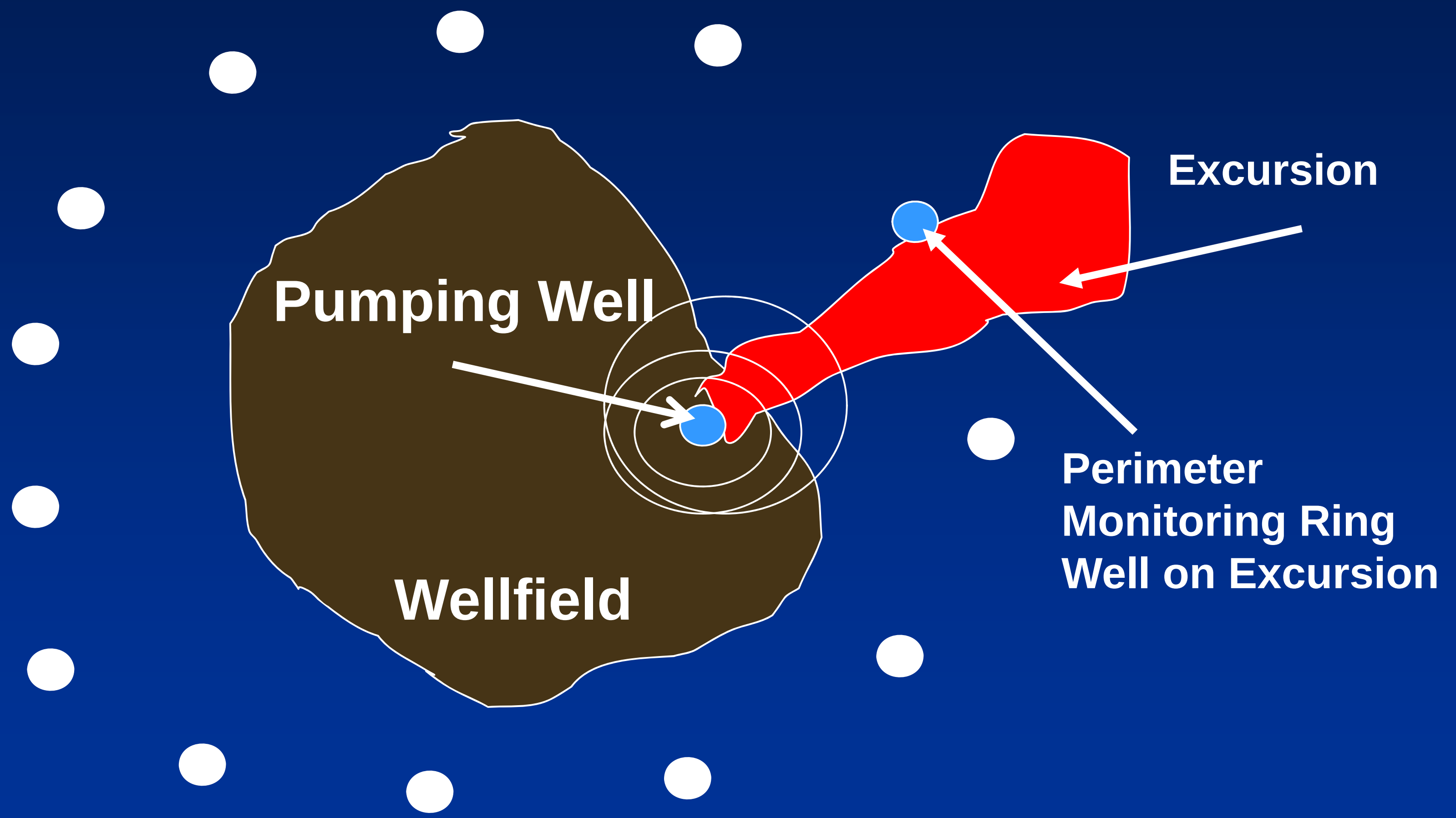
Confined aquifer :
Should not dewater unless piezometric surface drops below overlying aquitard



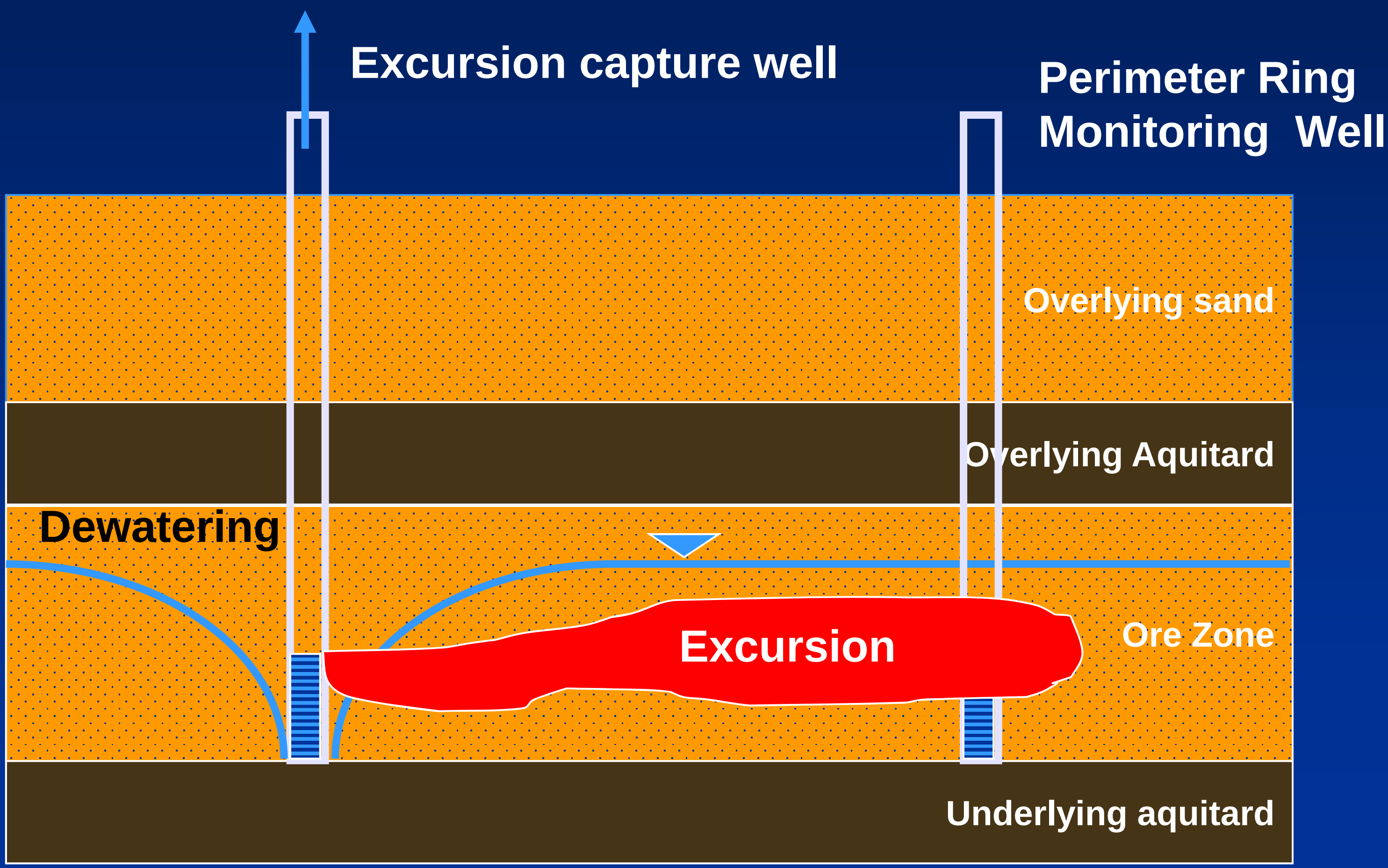
ISR Operation: Why is dewatering in an aquifer a safety issue?

- Dewatering of aquifer can limit extraction rates which can impact hydraulic control of wellfields and timelines for production and restoration.
- Dewatering can damage pumps, so hydraulic control of wellfield gradients may be compromised.
- Dewatering and limited extent of cone of depression may make it more difficult to prevent and capture excursions.
- Dewatering creates low hydrostatic head which affects dissolved oxygen solubility in ore zone and impact conductivity- “gas lock”.
- Free gas in the wellfield infrastructure can cause damage to pumps and piping. Pressure and flow gauges are not designed for two phase (gas and water) flow.

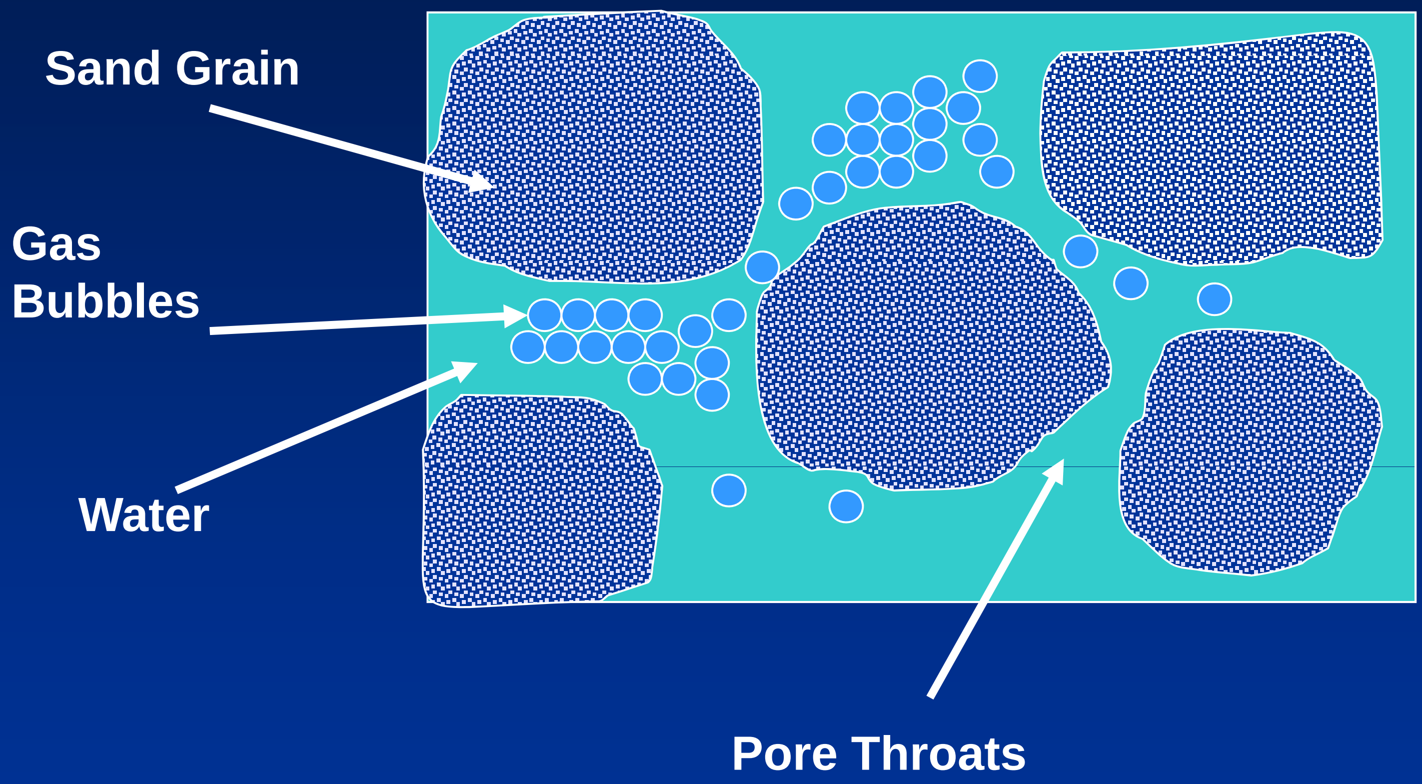
Lessons Learned : ISR Operation
Demonstrate ability to detect and correct excursions in all settings



Lessons Learned : ISR Operation Unconfined aquifers- Demonstrate how to detect and correct an excursion without dewatering



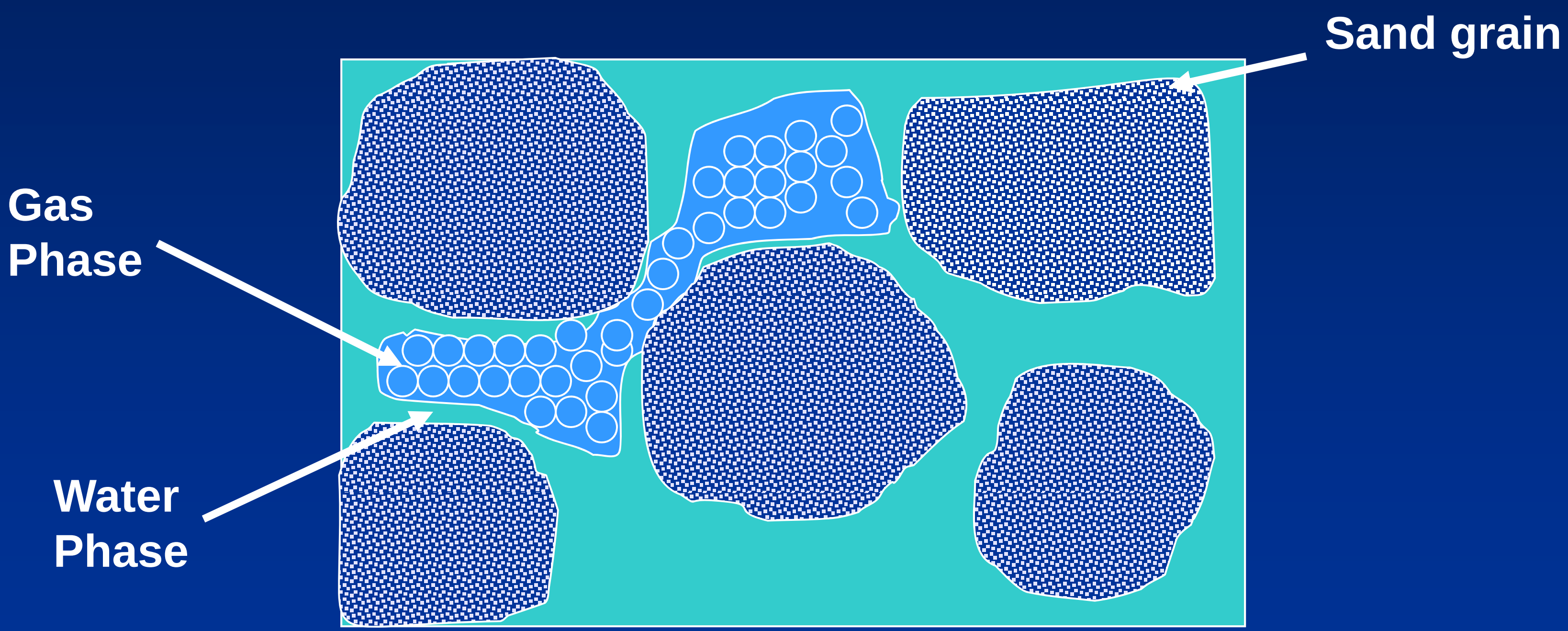
Lessons Learned : ISR Operation
"Gas Lock" reduction in conductivity from free gas in ore zone aquifer



Dissolved oxygen bubbles out of lixiviant when hydrostatic head reduced (unconfined or shallow confined aquifer) or hydrogen peroxide interacts with pyrite

Lessons Learned: ISR Operation
"Gas Lock" reduction in conductivity from free gas in ore zone aquifer

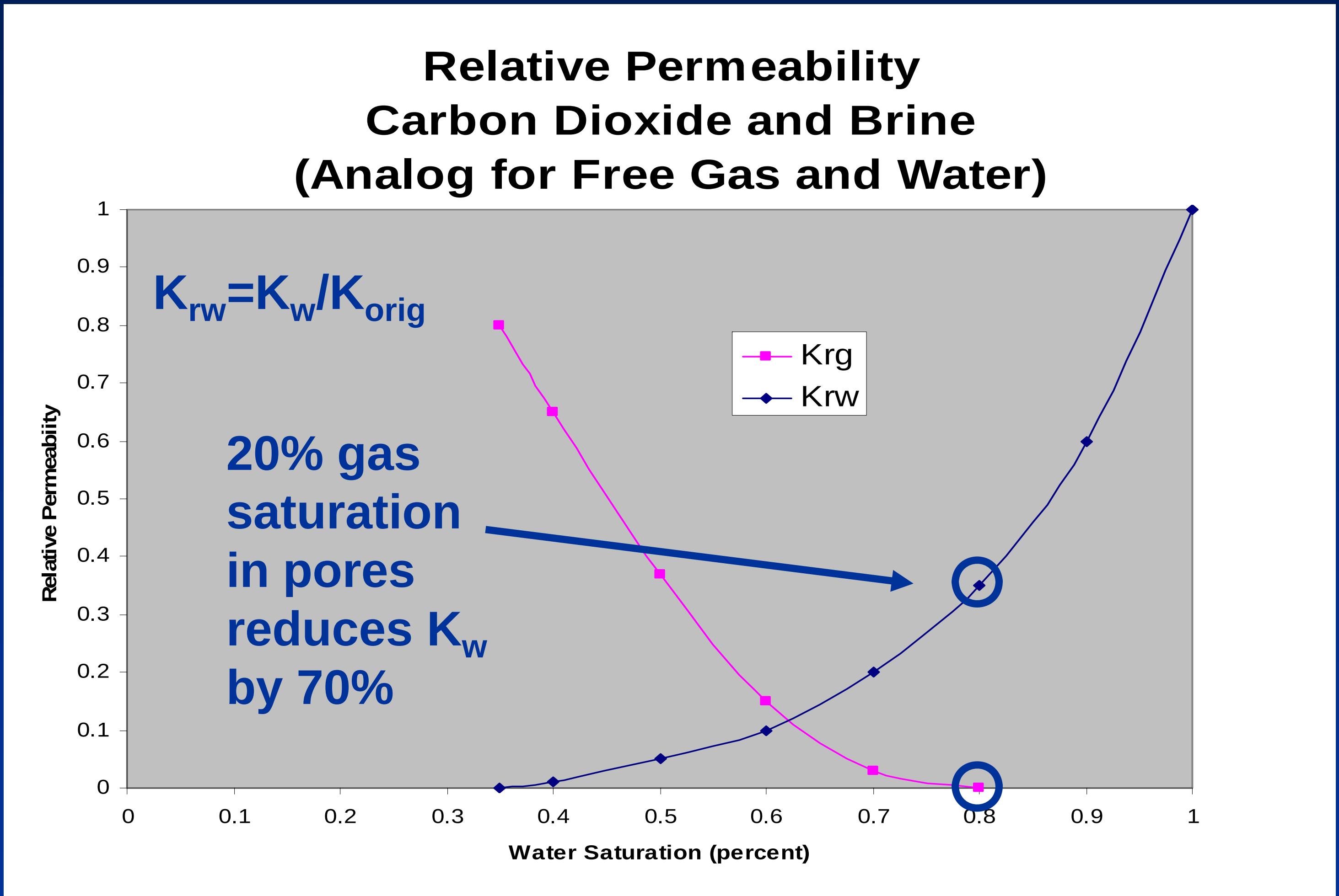
As gas bubbles continue to come out of solution, they combine to block pore throats or separate the water phase into smaller channels.



This creates a reduction in conductivity, known as "Gas Lock," which is dependent on saturation of the water and gas phases

Lessons Learned: ISR Operation
"Gas Lock" Impact on Conductivity in Aquifer

How much is the conductivity reduced?



From Benson et al, Lawrence Berkley National Lab, 2005

ISR Operation: Free Gas and "Gas Lock"

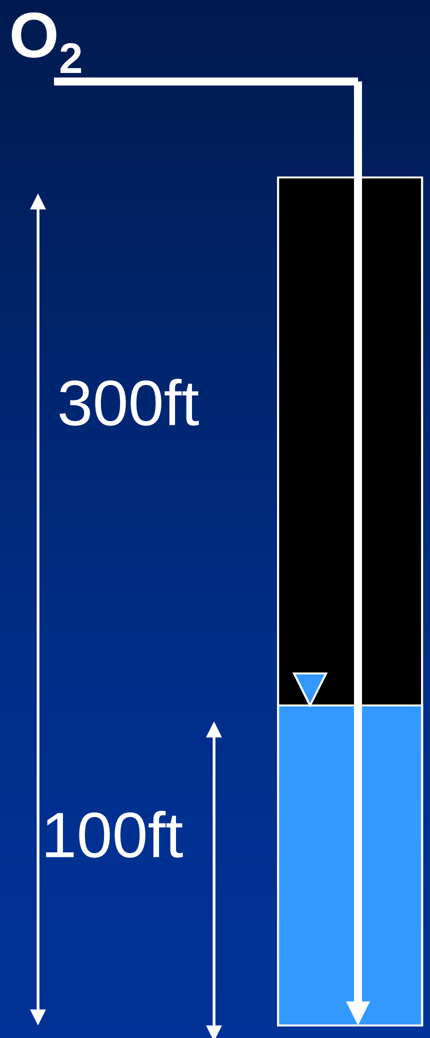
Why is it a Safety Issue ?

- Reductions in conductivity of ore zone can change flow system in an unpredictable manner which can influence flow control and may lead to excursions or bypassed zones.
- If free gas is released at the injection well, it can reduce injectivity and create back pressure which can quickly damage well if not detected.
- Gas produced at production well can cause simultaneous gas and water two phase flow that can damage piping, cause cavitation in pumps and affect pressure/flow measurements.

Lessons Learned: ISR Operation
Describe potential for free gas evolution, gas lock and actions to detect and correct

- **Assess solubility limits of dissolved oxygen in lixiviant and use oxygen concentrations which prevent gas from being released from solution at injection wells or ore zone**
- **Avoid use of hydrogen peroxide in low hydrostatic head aquifers with pyrites**
- **Watch for gas in injected and produced water at extraction wells**
- **Watch for two phase flow in wellfield infrastructure (pumps, flow /pressure gauges)**
- **Install pressure gauges on each well to detect pressure changes in wells and pipes directly**
- **If gas evolution an issue, cycle wells from injection/extraction to change water levels (pressure)**

Lessons Learned: ISR Operation
Demonstrate prevention and control free gas evolution in aquifer



Predict Oxygen Solubility and Design to Prevent Free Gas

Rule of thumb:
1 ppm dissolved oxygen/ foot of head

EXAMPLE: Injection Well

- **Fracture gradient limitation 1 psi/ft, so max injection pressure is 300 psi.**
- **Max well head pressure is therefore 300 psi- (300 ft*.433 psi/ft)=170psi.**
- **170 psi=392 feet so max O_2 can be 392 ppm at well head.**
- **If inject 392 ppm and solubility is 100 ppm (100ft): 292 ppm will come out of solution into ore zone aquifer**

Lessons Learned: ISR Operation
Hydrogen peroxide produces free gas phase in lixiviant if pyrite present

Hydrogen peroxide decomposes to form free oxygen, O_2, in the presence of pyrite, Fe S_2:

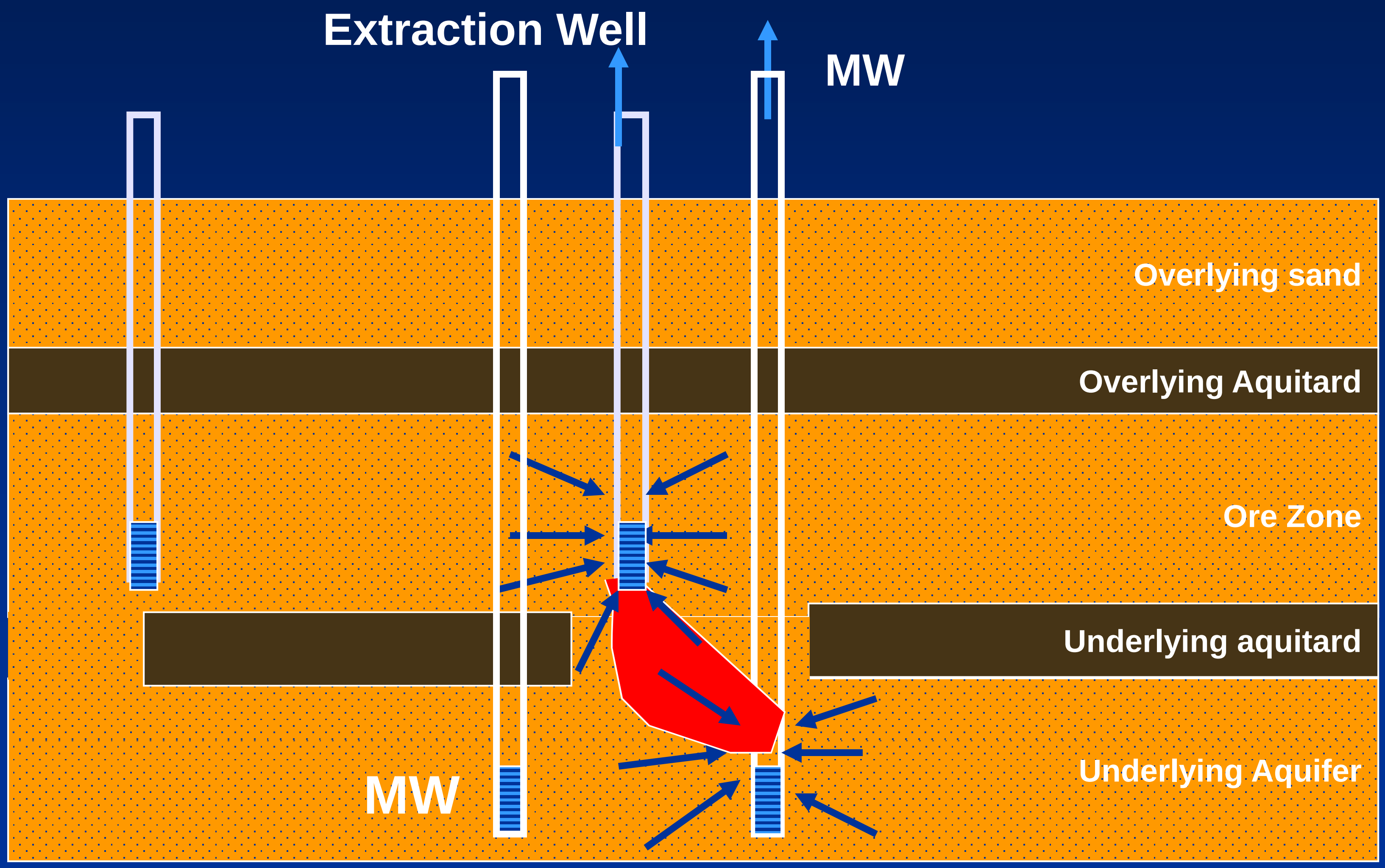
$$FeS_2 + 7.5H_2O_2 = Fe^{3+} + 2SO_4^{2-} + H^+ + 7H_2O$$

$$Fe^{3+} + 0.5H_2O_2 = Fe^{2+} + H^+ + 0.5O_2 \uparrow$$

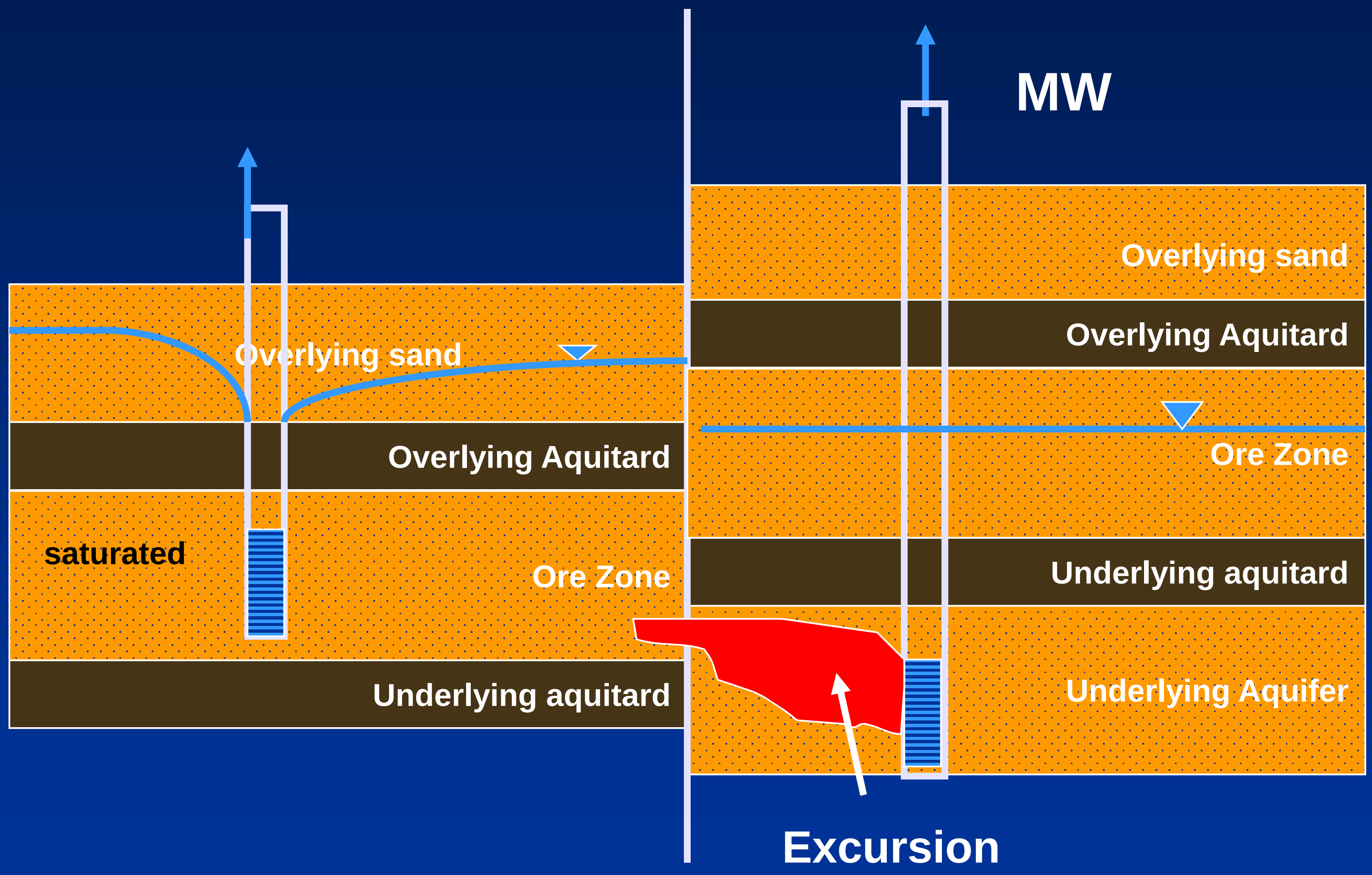
Free Phase Oxygen

Chirita, P., " A kinetic study of hydrogen peroxide decomposition in presence of pyrite," Chemical and Biochemical Engr Quarterly, Vol. 21, No. 3, pp. 257-264, 2007

Lessons Learned: ISR Operation
Demonstrate detection and correction of an excursion with thin or discontinuous aquitards



Lessons Learned: ISR Operation
Demonstrate detection and correction of excursions near faults



Lessons Learned: ISR Operation
Provide Wellfield Hydrologic Test
Data packages

- Provide supporting evidence for conclusions about hydrogeologic behavior of wellfield during operations
- Provide field tests- unconfined/confined, establish parameters, limiting extraction rate, etc
- Justify selection of MW locations
- Demonstrate inward gradient based on aquifer tests in wellfield
- Demonstrate lack of interaction with overlying and underlying aquifers through aquitards, across faults, etc
- Demonstrate connection with monitoring well ring from aquifer tests in wellfield

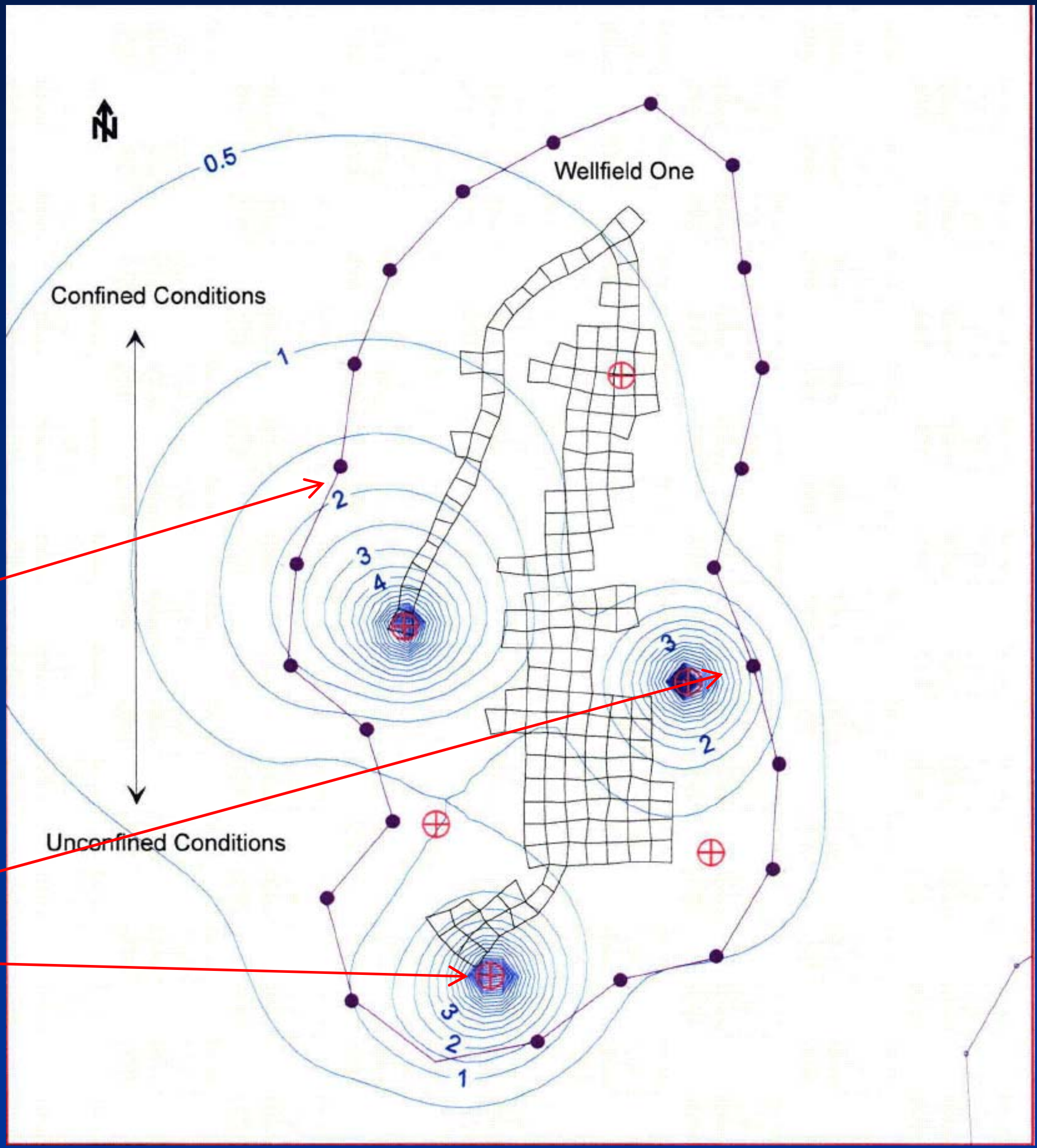
Lessons Learned: ISR Operation Provide Analytical or Numerical Groundwater Flow Modeling

Modeling provides supporting technical evidence for safety review conclusions:

Example: Simulation of pumping tests to show hydraulic connection of ore zone to MW ring

Confined aquifer : Larger piezometric surface drawdown reaches more wells on ring

Unconfined aquifer: Small cones of dewater drawdown reach a few wells on MW ring



Lessons Learned: ISR Restoration

- Provide average baseline water quality and restoration standards
- Provide appropriate pore volume/flare estimate in unconfined aquifer
- Address sweep of restoration fluids in an unconfined aquifer
- Estimate waste disposal capacity and contingency plan(e.g. injection wells, evaporation ponds, surge tanks, land application)
- Address long term excursions and their restoration
- Describe stability , long term monitoring and trend analysis

Lessons Learned: ISR Restoration
Determine Baseline Groundwater Quality

- Provide samples from wells in all aquifers within wellfield
  - Surficial Aquifer (s) - 4 samples/well , 2 weeks apart
  - Production Aquifer (s) - 4 samples/well , 2 weeks apart
  - Monitoring Ring Wells- 4 samples/well , 2 weeks apart
  - Overlying Aquifers (s) - 4 samples/well , 2 weeks apart
  - Underlying Aquifer(s) –4 samples/well , 2 weeks apart
- Measure NUREG- 1569 Table 2.7.3-1 parameters in each sample, unless non-detect in first two samples
- Apply wellfield average or well by well to establish baseline or offer other methods to establish baseline (EPA's ProUCL 4.0 (http://www.epa.gov/esd/tsc/software.htm))
- Apply appropriate statistics: Outlier analysis, zones of water quality (EPA-530-R-09-007, "Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities: Unified Guidance," March 2009.)

Lessons Learned: ISR Restoration Restoration Standards

- The NRC has notified licensees and applicants in Regulatory Information Summary, RIS 09-05, dated April 29, 2009 that the restoration standards listed in NUREG-1569, Section 6.1.3(4) are not consistent with those listed in 10 CFR Part 40, Appendix A and licensees and applicants and licensees must commit to achieve the restoration standards in Criterion 5B (5).
- These standards state the concentration of a hazardous constituent at the point of compliance must not exceed :

  (a) the Commission approved background concentration of that constituent in ground water;

  (b) the respective value in the table in paragraph 5C if the constituent is listed in the table and if the background level of the constituent is below the value listed or;

  (c) an alternative concentration limit established by the Commission.

ISR Restoration: ACLs

- ACLs may be approved using the criteria in 10 CFR Part 40, Appendix A Criterion 5B (6).
- An ACL is not a primary restoration goal and will only be considered after a licensee has demonstrated that primary restoration goals are not practically achievable at a specific site. ACLs that present no significant hazard may be proposed by the licensees for Commission consideration.
- The Commission may establish a site specific ACL for a hazardous constituent as provided in 5B(5) if it finds that the proposed limit is as low as reasonably achievable, after considering practicable corrective actions and that the constituent will not pose a substantial present or potential hazard to human health or the environment as long as the ACL is not exceeded.
- ACL application review procedures are available in the following documents:, NUREG-1620 and NUREG-1724. They will be added in the revision to NUREG-1569.

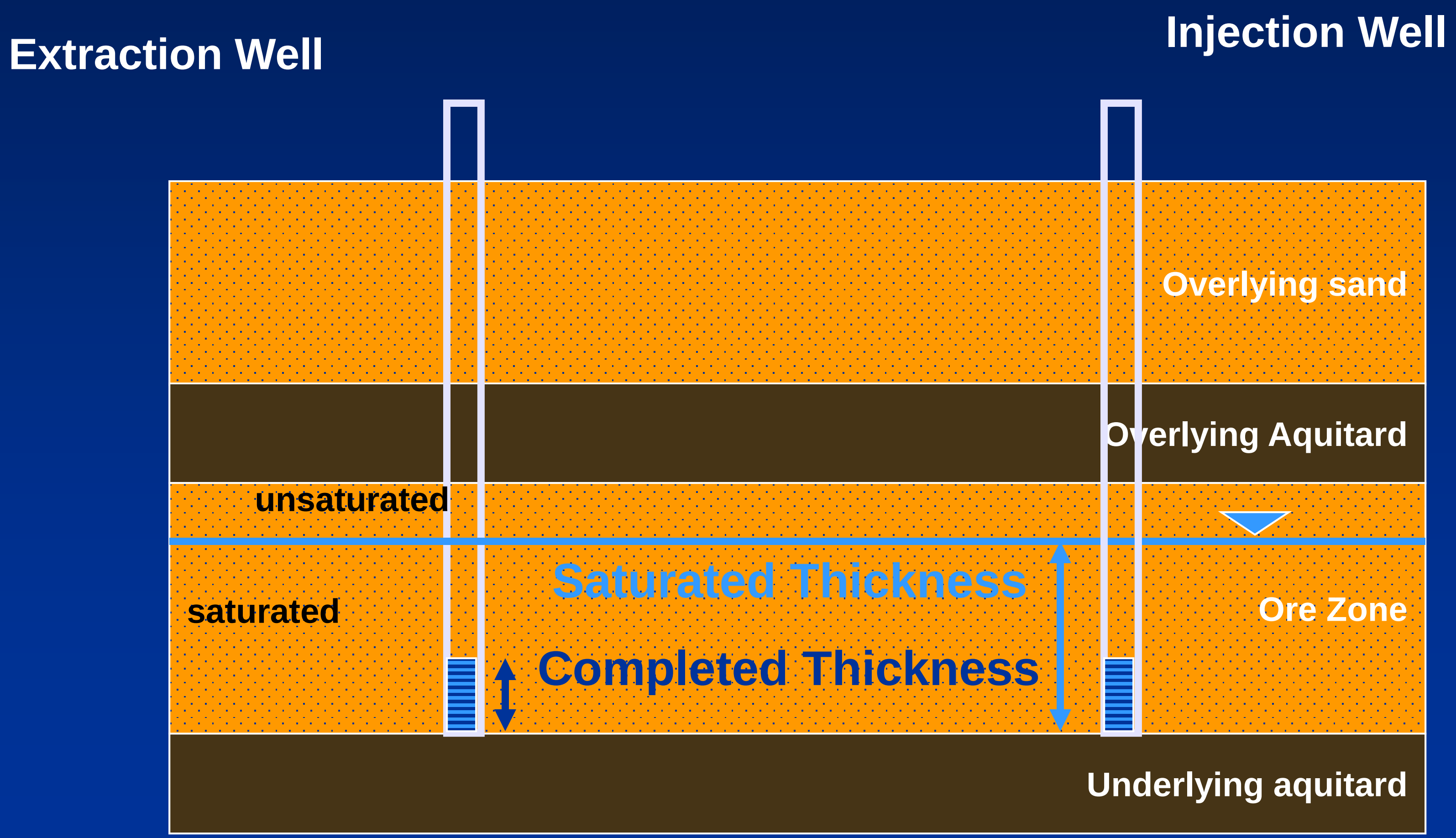
ISR Restoration: ACL application example format

(Patterned after NUREG1620 , Appendix K, Table K-1)

1. General Information
   a. Facility Description
   b. Current Ground Water Protection Standards
   c. Proposed ACLs
2. Hazard Assessment
   a. Constituents of Concern
   b. COC Characterization
   c. Health and Environmental Risks of Constituents
3. Exposure Assessment
   a. Transport and Pathway Assessment
   b. Human Exposure Potential
   c. Environmental Exposure Potential
   d. Consequences of Exposure
4. Restoration Assessment
   a. Previous and Current Restoration Actions
   b. Potential Restoration Actions
   c. Feasibility of Restoration Actions
   d. Costs/Benefits of Restoration Actions
   e. ALARA demonstration
5. Alternative Concentration Limit(s)
   a. Proposed ACLs
   b. Proposed Implementation of Ground Water Monitoring Measures

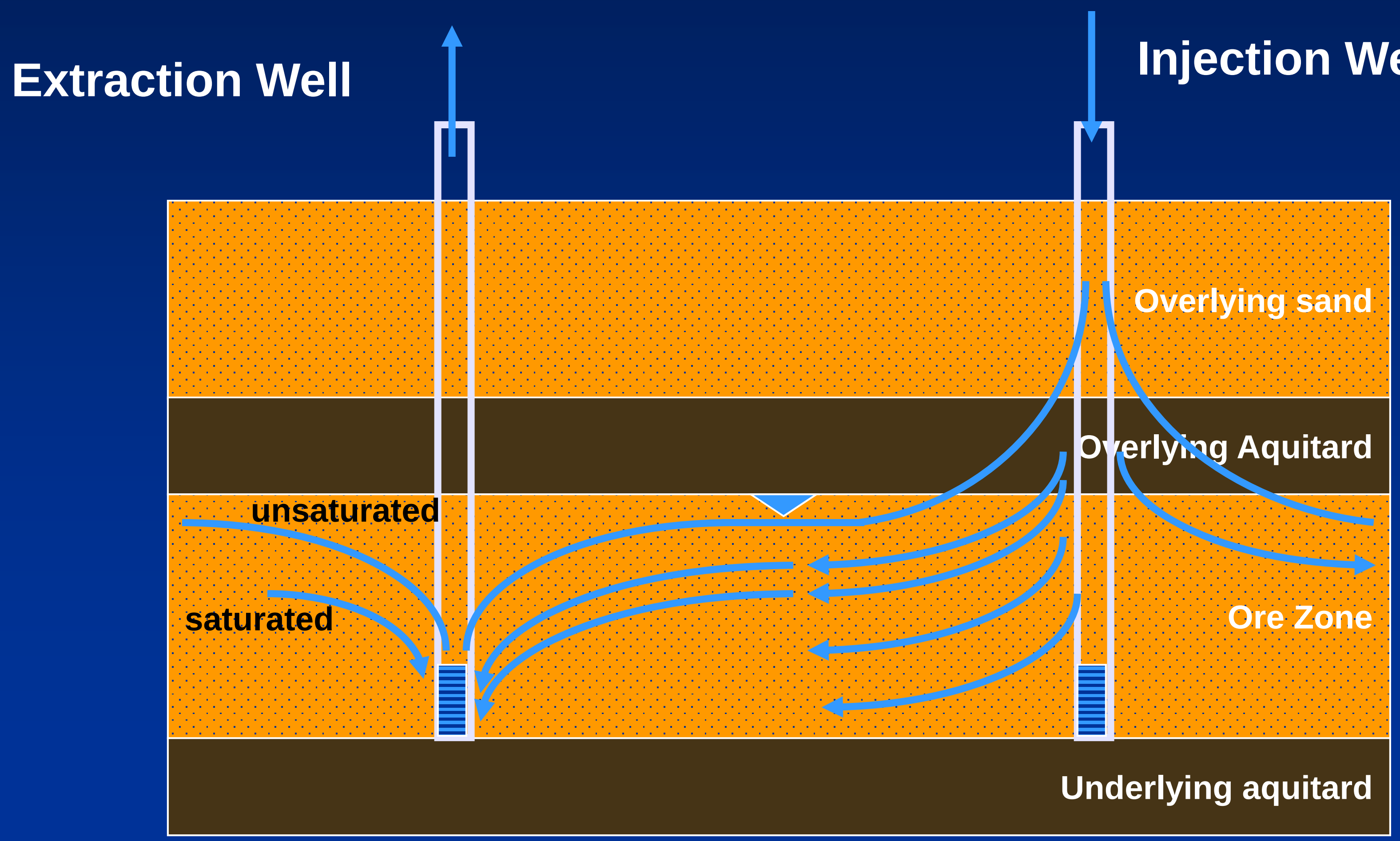
Lessons Learned: ISR Restoration Estimate Pore Volume/Flare in Unconfined Aquifer

PV= Area * *Average Completed Thickness* * Porosity * Flare

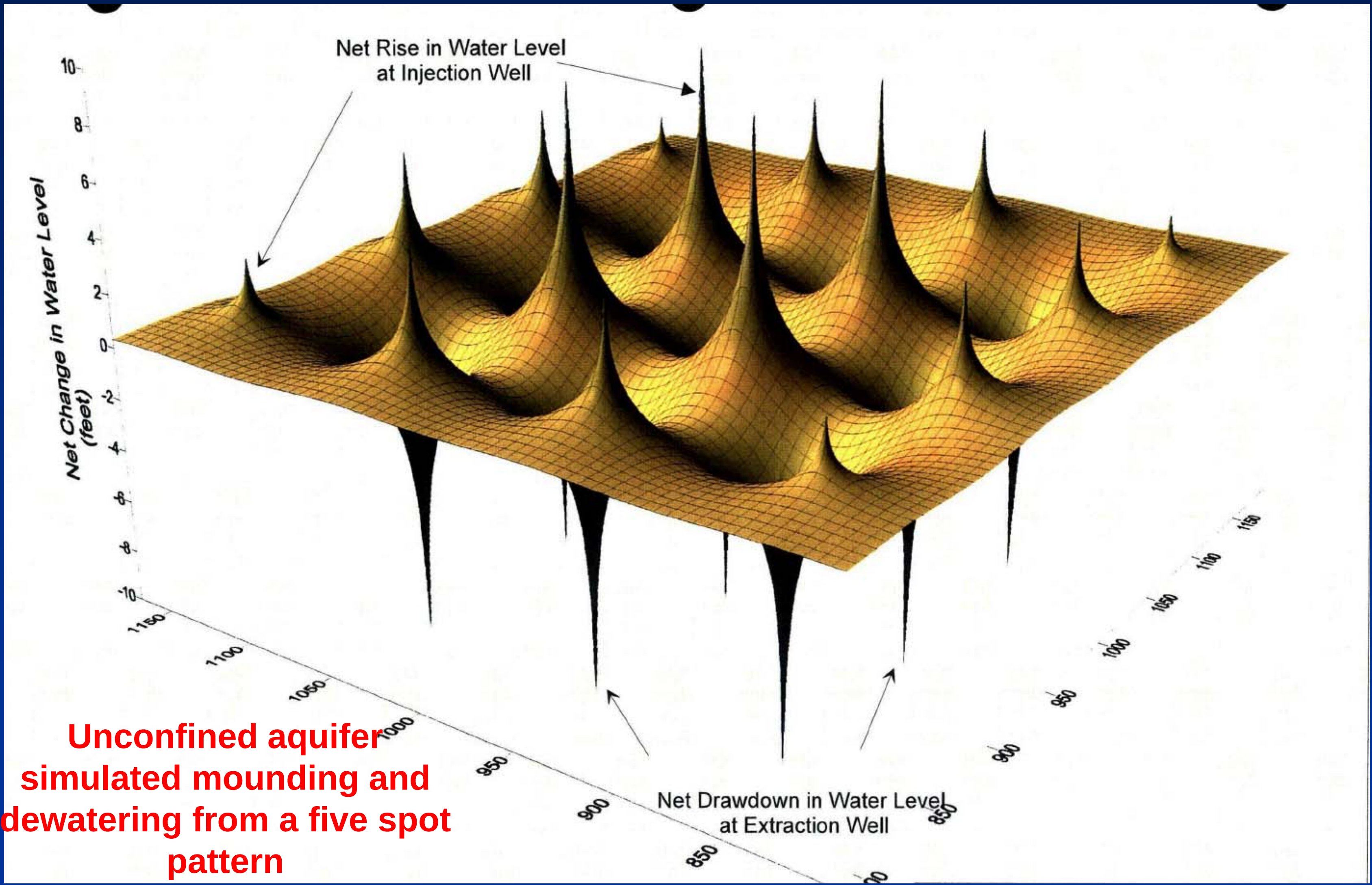


Lessons Learned: ISR Restoration Estimate Pore Volume/Flare in Unconfined Aquifer

Injection/Extraction in Unconfined Aquifer :
Vertical flow contacts more than completed thickness
PV= Area * *Saturated thickness* * Porosity * Flare (vertical/horizontal)



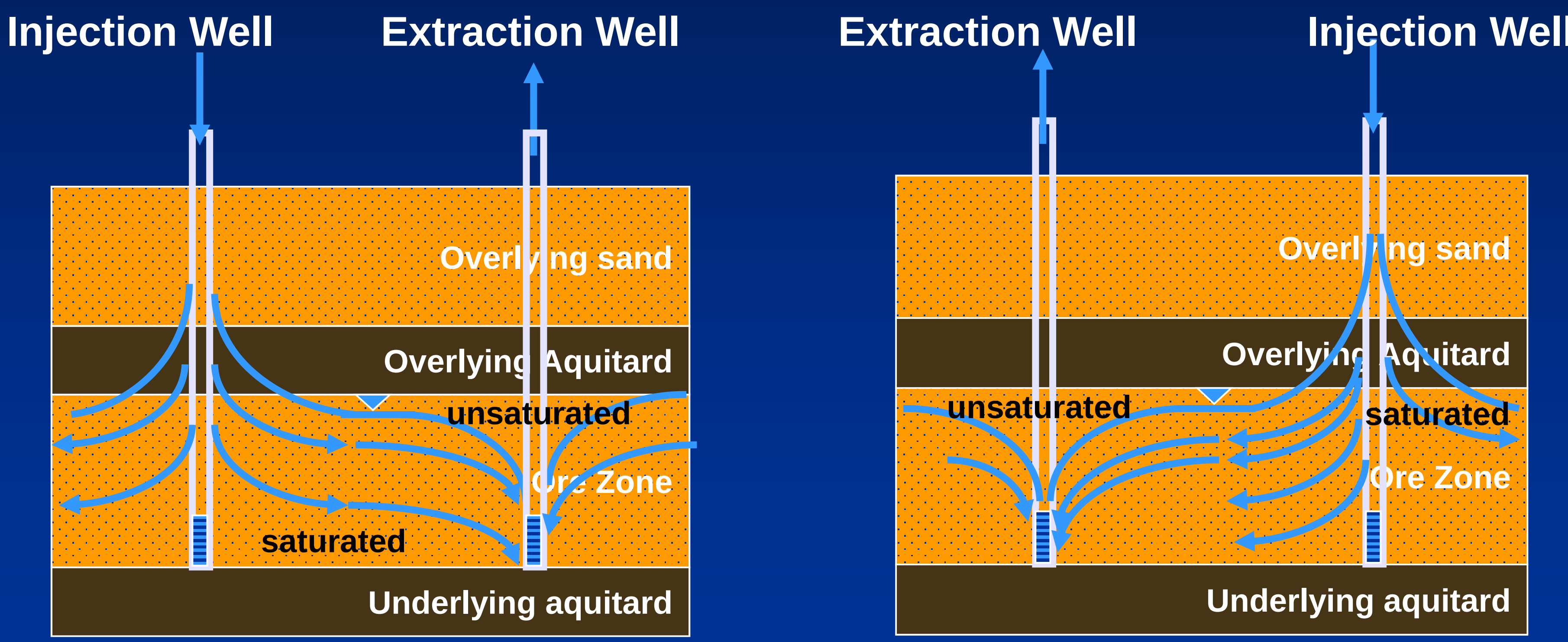
Lessons Learned: ISR Restoration Unconfined aquifer mounding/dewatering impacts sweep/contact of ore zone with restoration fluids.



Unconfined aquifer simulated mounding and dewatering from a five spot pattern

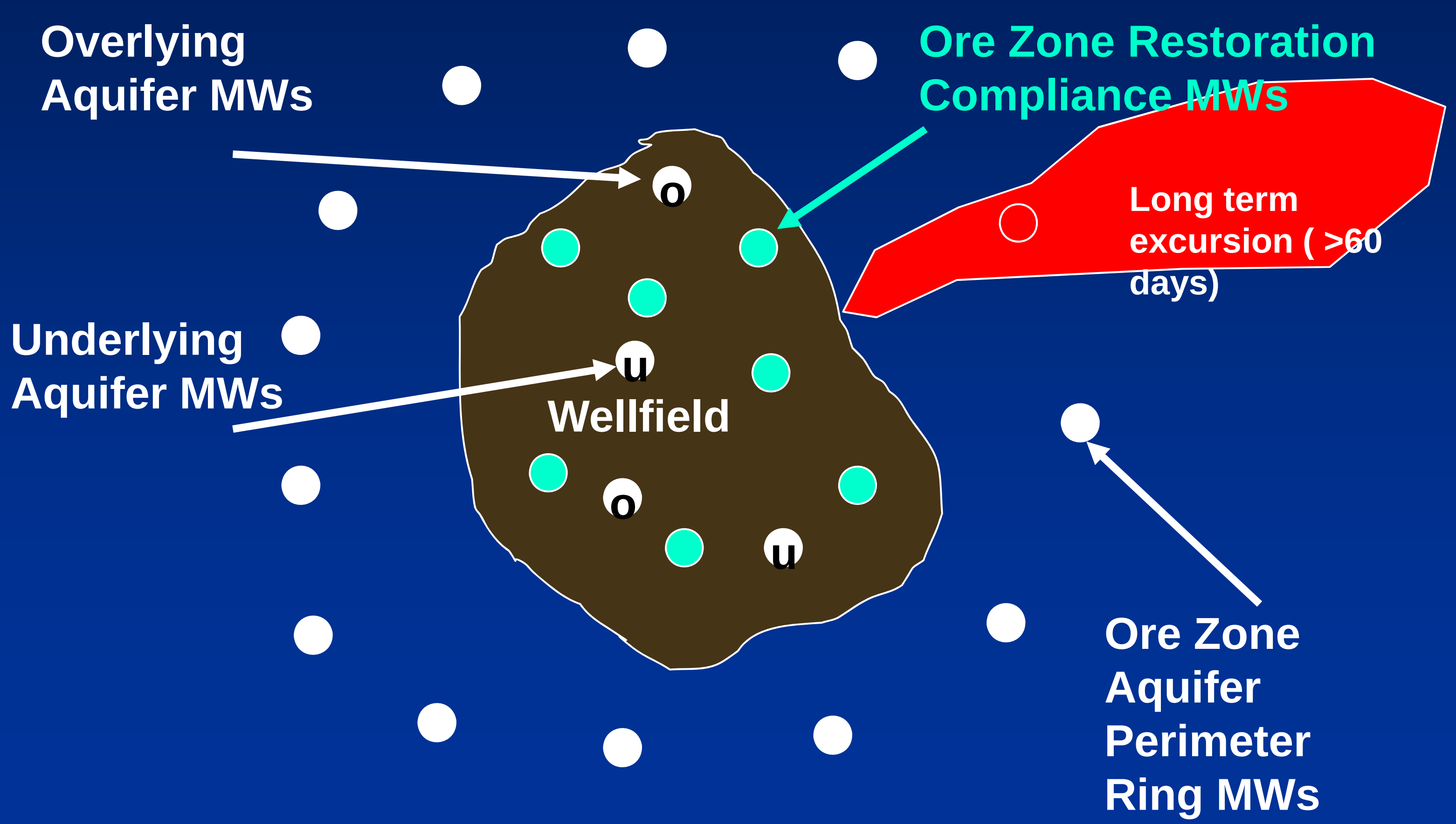
Lessons Learned: ISR Restoration
Demonstrate sweep of restoration fluids in an unconfined aquifer

Possible Solution: Flip/pulse wells to ensure contact of all portions of aquifer with restoration fluids.



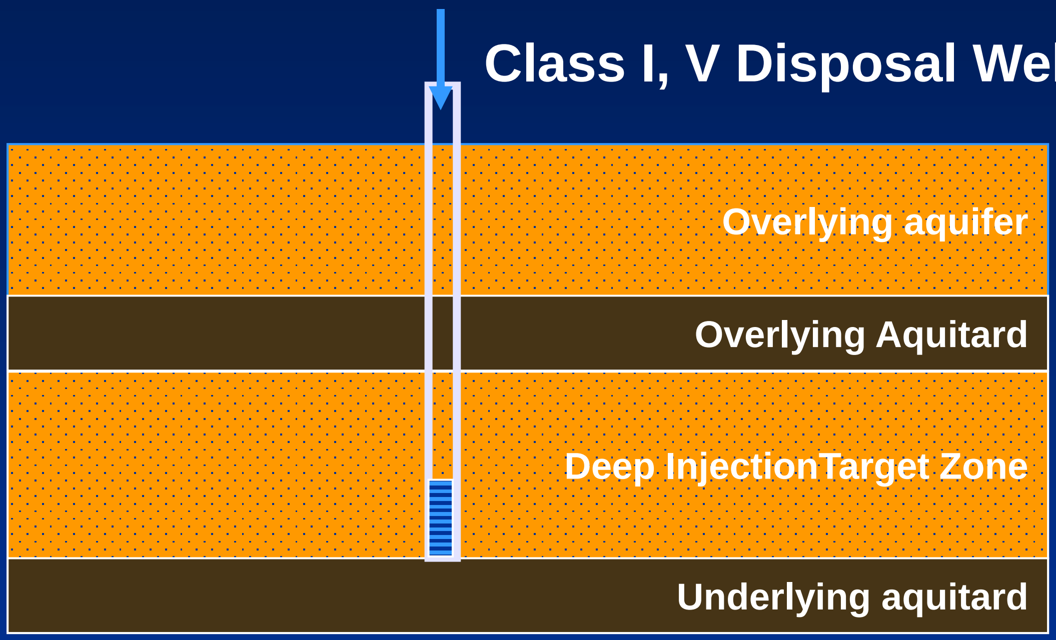
Lessons Learned: ISR Restoration
Address restoration of long term excursions (>60 days)

Wells on long term excursion must be characterized and corrected back to Criterion 5B (5) Standards



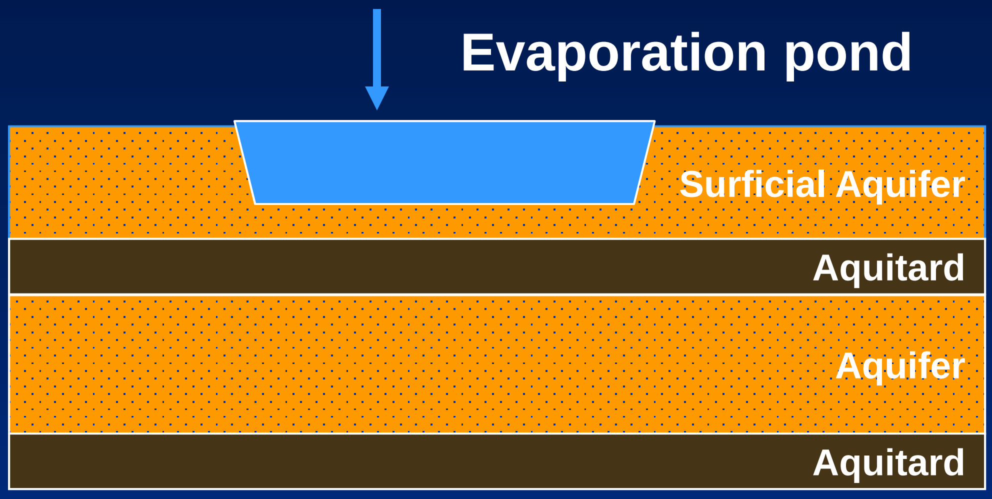
Lessons Learned: ISR Restoration Demonstrate Waste Water Disposal Capacity

- Provide number and locations of disposal wells
- Provide information on target formations
- Provide justification for estimates of each disposal well's capacity
- Provide water balance showing sufficient capacities for operation and restoration and contingency plans
- Provide Disposal Waste and ALARA analysis: 10CFR20.2002



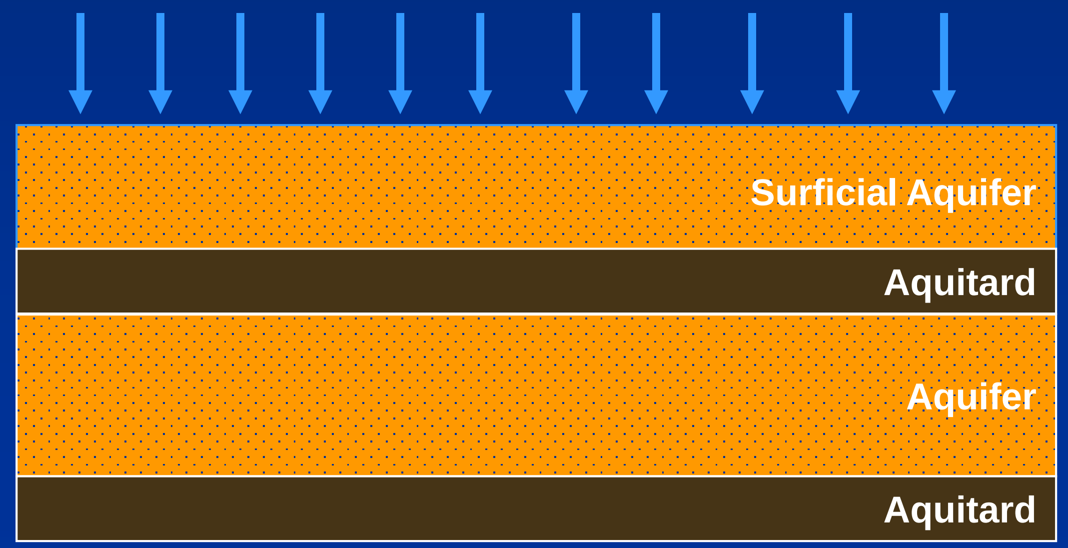
Lessons Learned: ISR Restoration Demonstrate Waste Water Disposal Capacity

Evaporation pond



Surge tanks

Land Application



- **Provide water balance showing pond capacity/land app adequate**
- **Provide contingency capacity**
- **Provide waste and ALARA analysis**
- **Land application guidance will be added to NUREG-1569**

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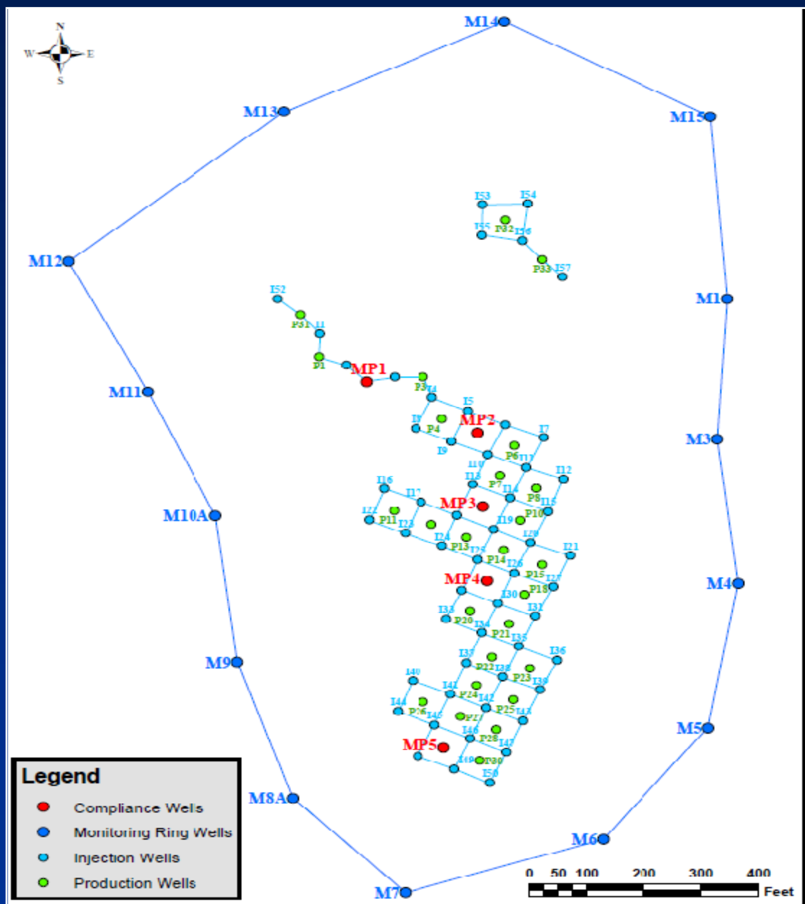
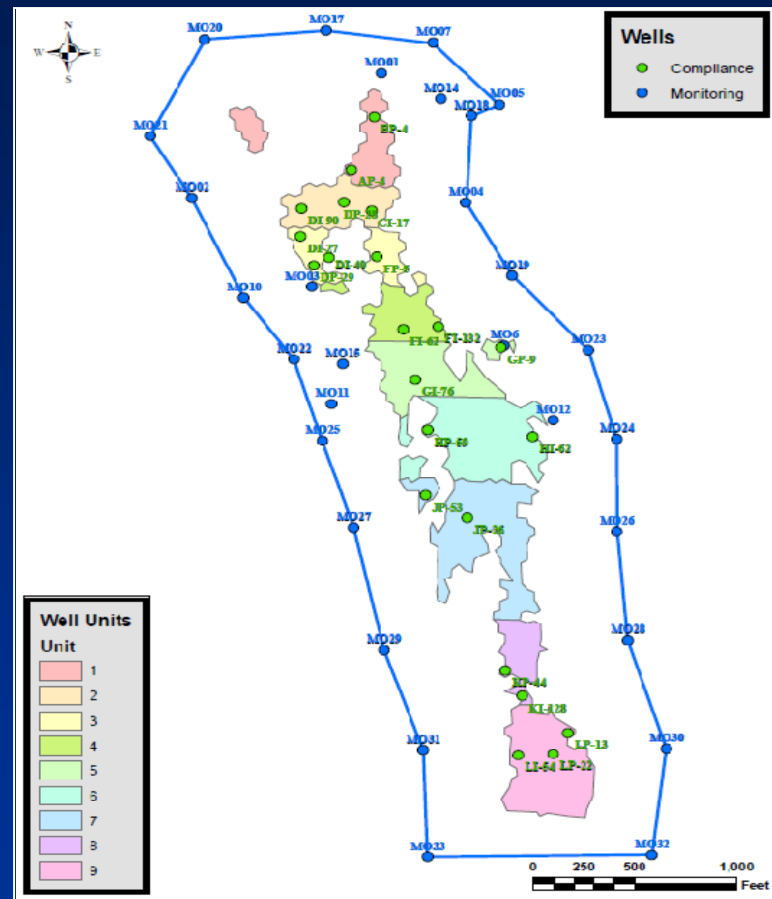
Lessons Learned: ISR Restoration Stability monitoring trend analysis to determine presence of Statististically Significant Increasing trends (SSI)

- Recommend trend analysis using linear regression analysis provided by EPA in Chapter 17 of EPA-530-R-09-007, "Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities: Unified Guidance," March 2009.
- Trend analysis is a hypothesis test for the statistical identification of no significant trend, a statistically significant decreasing trend (SSD), or a statistically significant increasing trend (SSI) in the monitoring data.
- Tests the slope coefficient, *m*, from the linear regression trend line through the stability data, $y=mx+b$, using a specially constructed Student's t-test, to evaluate if trend is statistically different from zero.
- Useful for mildly variable sample data for which the regression residuals are normally distributed.
- Linear Trend Analysis of NRC approved restorations: Reviewed and applied analysis to three specific constituents: TDS, Uranium, and Radium 226 for individual compliance wells in each mine unit approved by NRC.

ISR Restoration: Stability monitoring trend analysis Field data from three ISR operations with NRC approved restorations

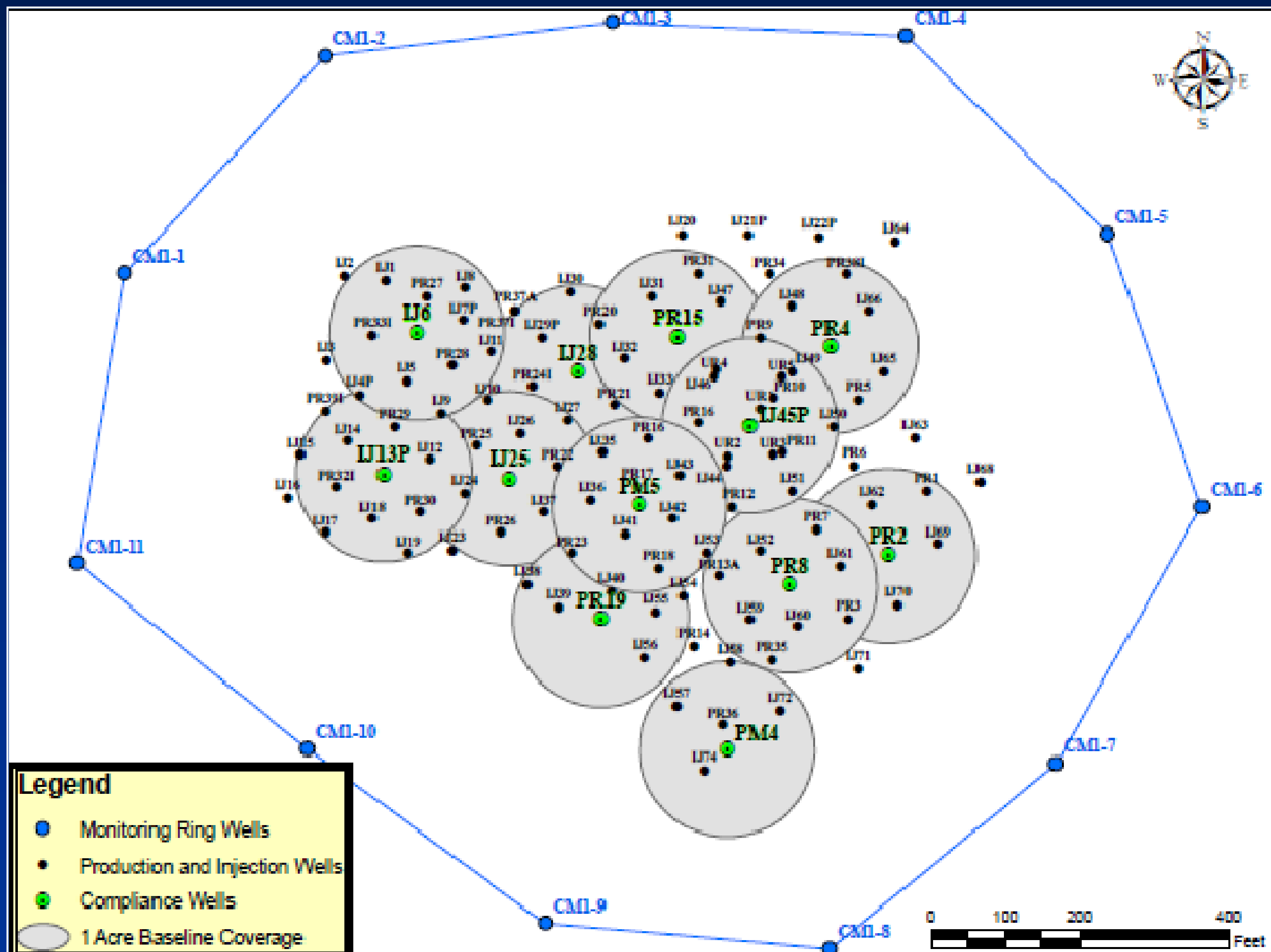




Power Resources , Inc
Smith Ranch –Highland Uranium Project MUA (2.8 acres, PV=4.1 mgal)

Irigaray MUs 1-9 (MUs = 1-4.7 acres, PVs =4.5-13.3 mgal)

ISR Restoration: Stability monitoring trend analysis Field data from three ISR operations with NRC approved restorations



Crow Butte Resources
MU1 (MU=9.3 acres, PV= 17.2 mgal)

ISR Restoration: Uranium, Radium and TDS Stability Trend Analysis for NRC Approved Restorations

Table 7. Crow Butte Resources MU1 Total Dissolved Solids Restoration Stability Data and Stability Trend Analysis

CBR MU1	Days	0	27	55	90	118	146	1252	1266	1280	Regression line	m (slope)	$s_e(m)$	$t_b=m/s_e(m)$	Students t_{cp} (99%)	Conclusion
TDS (mg/l)	PR-15	606	651	670	675	685	669	763	699	720	TDS=.059t+654	0.0590	0.0312	1.8938	2.8960	**no significant trend**
TDS (mg/l)	IJ-13	1060	1080	1110	1100	1120	1080	1310	1310	1320	TDS=.186t+1078	0.1860	0.0182	10.2182	2.8960	***SSI***
TDS (mg/l)	PR-8	1160	1160	1150	1160	1190	1160	1230	1230	1210	TDS=.05t+1159	0.0500	0.0140	3.5757	2.8960	***SSI***
TDS (mg/l)	IJ-25	1030	1050	1050	1040	1070	1030	1120	1110	1110	TDS=.057t+1041	0.0570	0.0145	3.9346	2.8960	***SSI***
TDS (mg/l)	IJ-28	1010	1050	1080	1050	1060	1020	1060	1080	1110	TDS=.032t+1042	0.0320	0.0282	1.1351	2.8960	**no significant trend**
TDS (mg/l)	IJ-45	1060	1070	1090	1090	1080	1090	1050	1040	1040	TDS=-.029t+1081	-0.0290	0.0134	-2.1573	2.8960	**no significant trend**

Table 8. Crow Butte Resources MU1 Uranium Restoration Stability Data and Stability Trend Analysis

CBR MU1	Days	0	27	55	90	118	146	1252	1266	1280	1308	Regression line	m (slope)	$s_e(m)$	$t_b=m/s_e(m)$	Students t_{cp} (99%)	Conclusion
Ur(mg/l)	PR-15	0.3	0.4	0.4	0.5	0.8	0.9	0.5	0.4	0.4	0.3	Ur=-.0001t+.549	-0.0001	0.0003	-0.3379	2.8960	**no significant trend**
Ur(mg/l)	IJ-13	0.2	1.3	1.6	1.5	1.8	1.7	1.7	1.6	1.8	2.2	Ur=.0004t+1.29	0.0004	0.0005	0.7806	2.8960	**no significant trend**
Ur(mg/l)	PR-8	2.3	2.1	1.6	1.1	1.6	1.6	1.9	1.6	1.5	1.6	Ur=.00008t+1.73	0.0001	0.0004	0.1974	2.8960	**no significant trend**
Ur(mg/l)	IJ-25	0.8	1	1	0.7	1.1	1.3	2.2	1.8	1.6	1.5	Ur=.0007t+.935	0.0007	0.0003	2.5829	2.8960	**no significant trend**
Ur(mg/l)	IJ-28	0.5	0.7	0.7	0.5	0.8	0.7	2.8	2.4	2.4	2.3	Ur=.0015t+.543	0.0015	0.0002	7.8645	2.8960	***SSI***
Ur(mg/l)	IJ-45	0.9	1.2	1.2	0.8	1.2	1.2	2.1	1.8	1.7	1.7	Ur=.0006t+1.03	0.0006	0.0002	2.9919	2.8960	***SSI***

Table 9. Crow Butte Resources MU1 Radium 226 Restoration Stability Data and Stability Trend Analysis

CBR MU1	Days	0	27	55	90	118	146	1252	1266	1280	1308	Regression line	m (slope)	$s_e(m)$	$t_b=m/s_e(m)$	Students t_{cp} (99%)	Conclusion
RA 226 (pCi/l)	PR-15	13	25	30	30	26	32	22	20	17	13	Ra=-.0063t+26.3	-0.0063	0.0139	-0.4547	2.8960	**no significant trend**
RA 226 (pCi/l)	IJ-13	376	665	764	770	920	849	744	778	852	778	Ra=.0664t+712.8	0.0664	0.1618	0.4104	2.8960	**no significant trend**
RA 226 (pCi/l)	PR-8	204	190	184	199	206	192	218	239	251	310	Ra=.049t+192	0.0493	0.0262	1.8834	2.8960	**no significant trend**
RA 226 (pCi/l)	IJ-25	253	218	236	225	242	202	216	210	203	231	Ra=-.0125t+230.5	-0.0125	0.0171	-0.7331	2.8960	**no significant trend**
RA 226 (pCi/l)	IJ-28	160	192	212	203	206	185	169	188	207	180	Ra=-.0051t+193	-0.0051	0.0192	-0.2653	2.8960	**no significant trend**
RA 226 (pCi/l)	IJ-45	445	431	447	468	509	487	418	405	451	407	Ra=-.035t+46.6	-0.0346	0.0297	-1.1635	2.8960	**no significant trend**

ISR Restoration: Uranium, Radium and TDS Stability Trend Analysis for NRC Approved Restorations

Table 10. Smith Ranch Highlands Uranium Project MUA Total Dissolved Solids (TDS) Restoration Stability Data and Stability Trend Analysis

SRHUP MUA	Days	0	176	239	2268	2606	3003	3369	3737		Regression line	m (slope)	$s_e(m)$	$t_b=m/s_e(m)$	Students t_{cp} (99%)	Conclusion
TDS (mg/l)	MP-1	366	384	356												**insufficent data**
TDS (mg/l)	MP-2	392	438	435												**insufficent data**
TDS (mg/l)	MP-3	420	309	413												**insufficent data**
TDS (mg/l)	MP-4	443	488	441	485	472	502	509	502		TDS=.0134t+454	0.0134	0.0074	1.8098	2.9980	**no significant trend**
TDS (mg/l)	MP-5	431	447	425												**insufficent data**

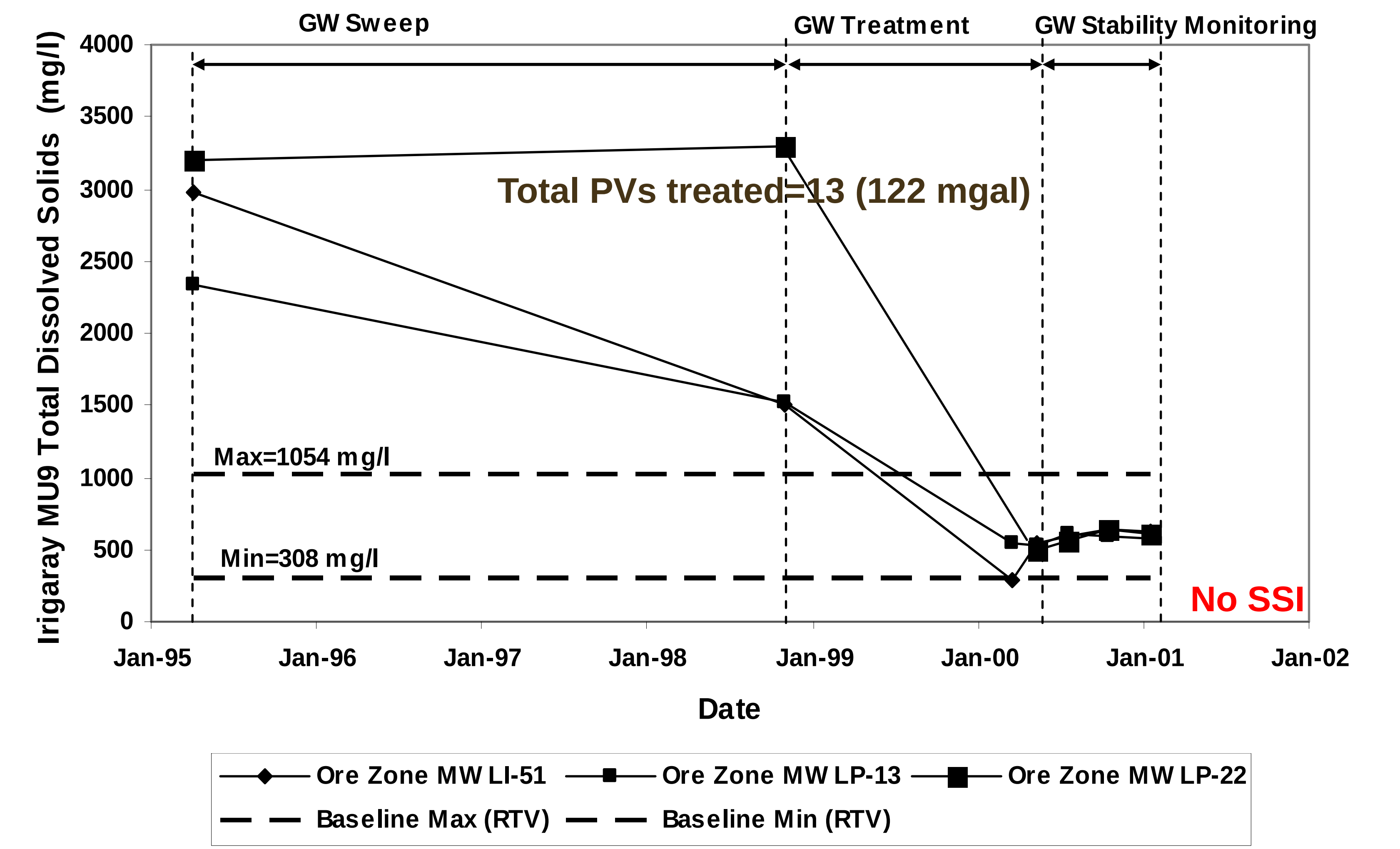
Table 11. Smith Ranch Highlands Uranium Project MUA Uranium Restoration Stability Data and Stability Trend Analysis

SRHUP MUA	Days	0	176	239	1241	2268	2606	3003	3369	3737		Regression line	m (slope)	$s_e(m)$	$t_b=m/s_e(m)$	Students t_{cp} (99%)	Conclusion
Ur(mg/l)	MP-1	0.26	0.19	0.29													**insufficient data**
Ur(mg/l)	MP-2	0.17	0.17	0.17													**insufficient data**
Ur(mg/l)	MP-3	0.69	0.69	0.46													**insufficient data**
Ur(mg/l)	MP-4	8.2	8.75	9.9	10.5	11.9	13.2	13.1	11.8	14.6		Ur=.0014t+8.79	0.0014	0.0004	3.7112	2.9980	***SSI***
Ur(mg/l)	MP-5	8.35	9.17	9.3													**insufficient data**

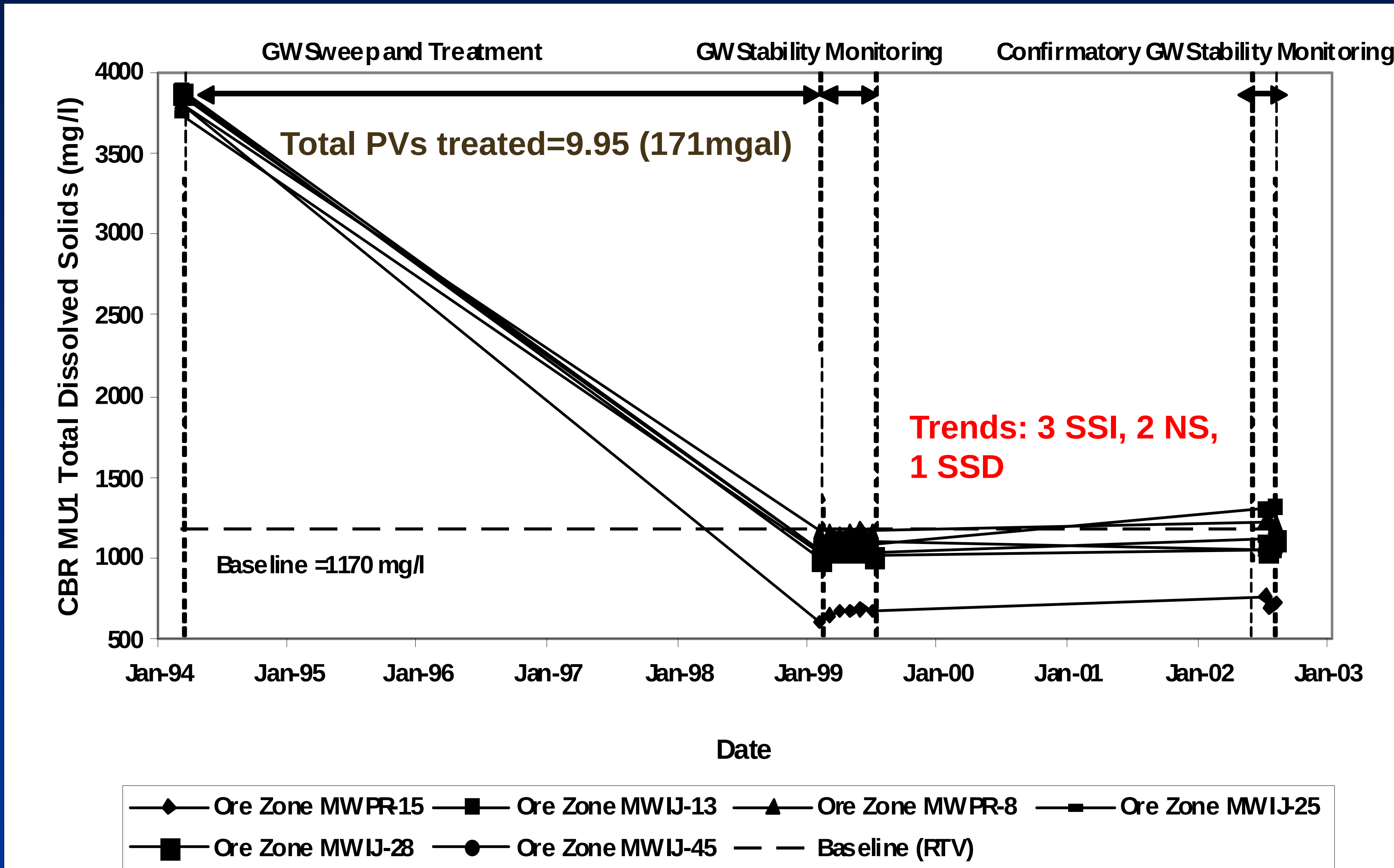
Table 12. Smith Ranch Highlands Uranium Project MUA Radium 226 Restoration Stability Data and Stability Trend Analysis

SRHUP MUA	Days	0	176	239	2268	2606	3003	3369	3734			Regression line	m (slope)	$s_e(m)$	$t_b=m/s_e(m)$	Students t_{cp} (99%)	Conclusion
RA 226 (pCi/l)	MP-1	293	300	359													**insufficient data**
RA 226 (pCi/l)	MP-2	934	996	990													**insufficient data**
RA 226 (pCi/l)	MP-3	784	665	749													**insufficient data**
RA 226 (pCi/l)	MP-4	3220	3687	3360	3580	1340	3440	3830	3140			Ra=-.074t+3342	-0.0740	0.3559	-0.2079	2.9980	**no significant trend**
RA 226 (pCi/l)	MP-5	532	585	382													**insufficient data**

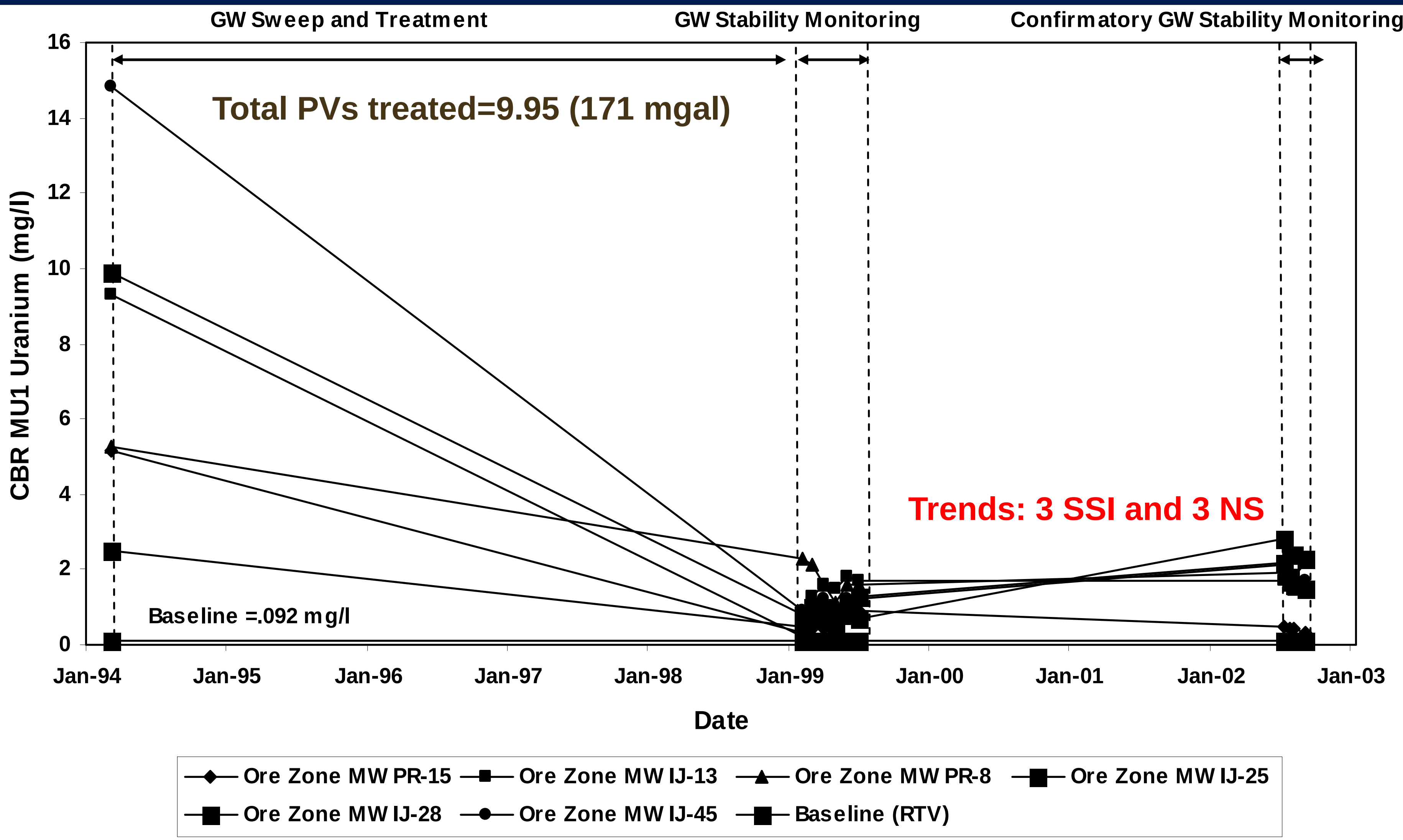
ISR Restoration: Short Term Stability Monitoring Trend Analysis



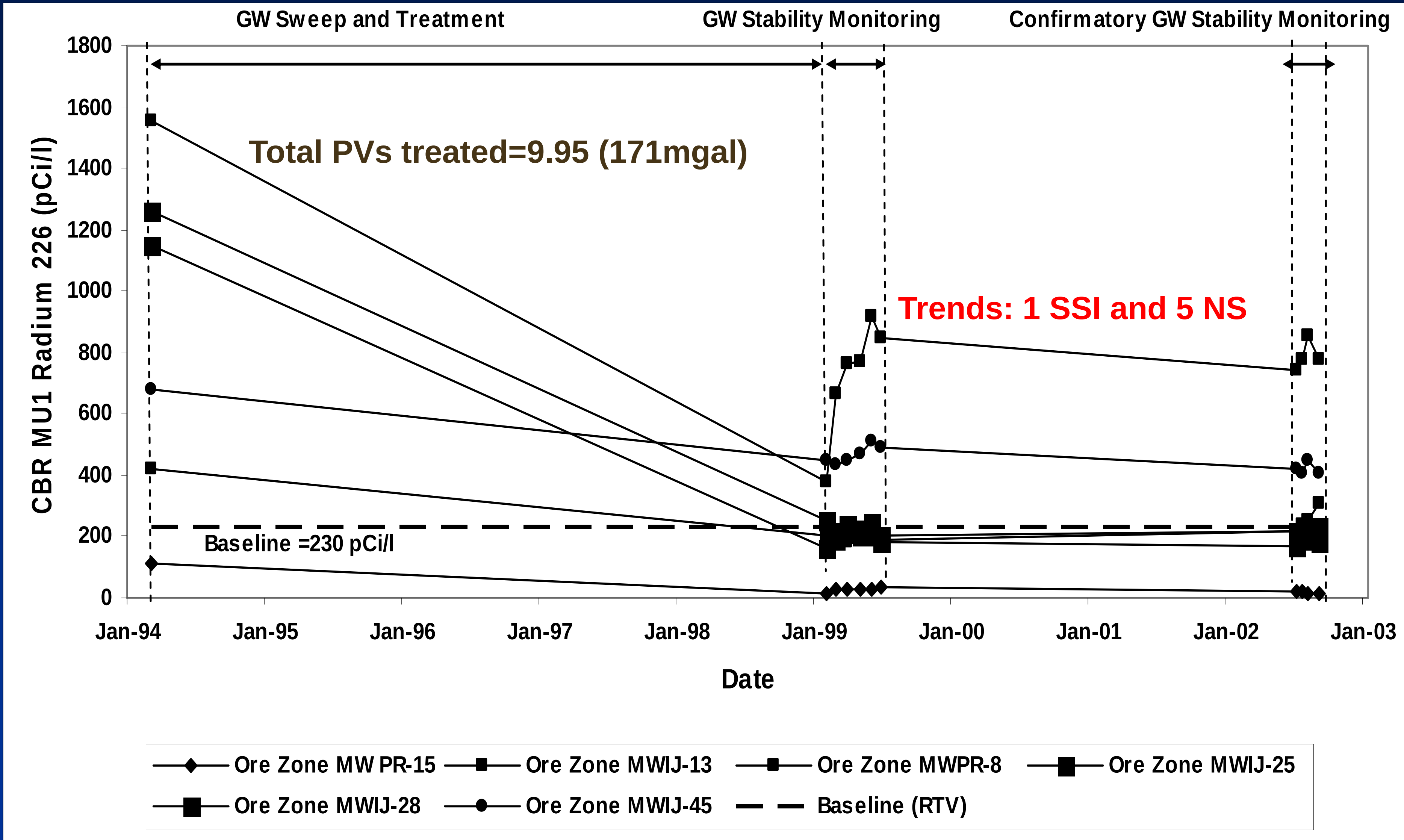
ISR Restoration: Stability and Long Term Monitoring Trend Analysis



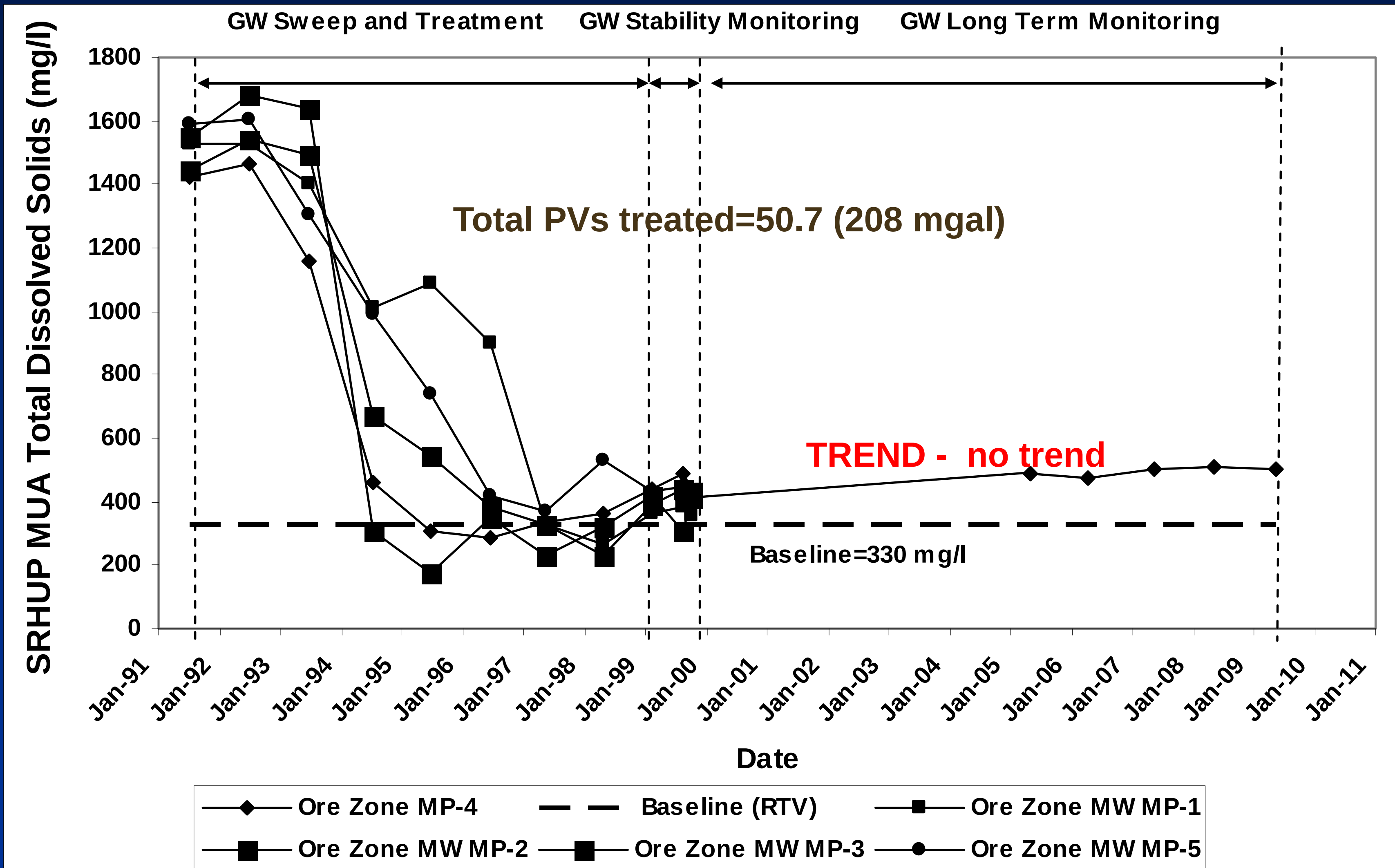
ISR Restoration: Stability and Long Term Monitoring Trend Analysis



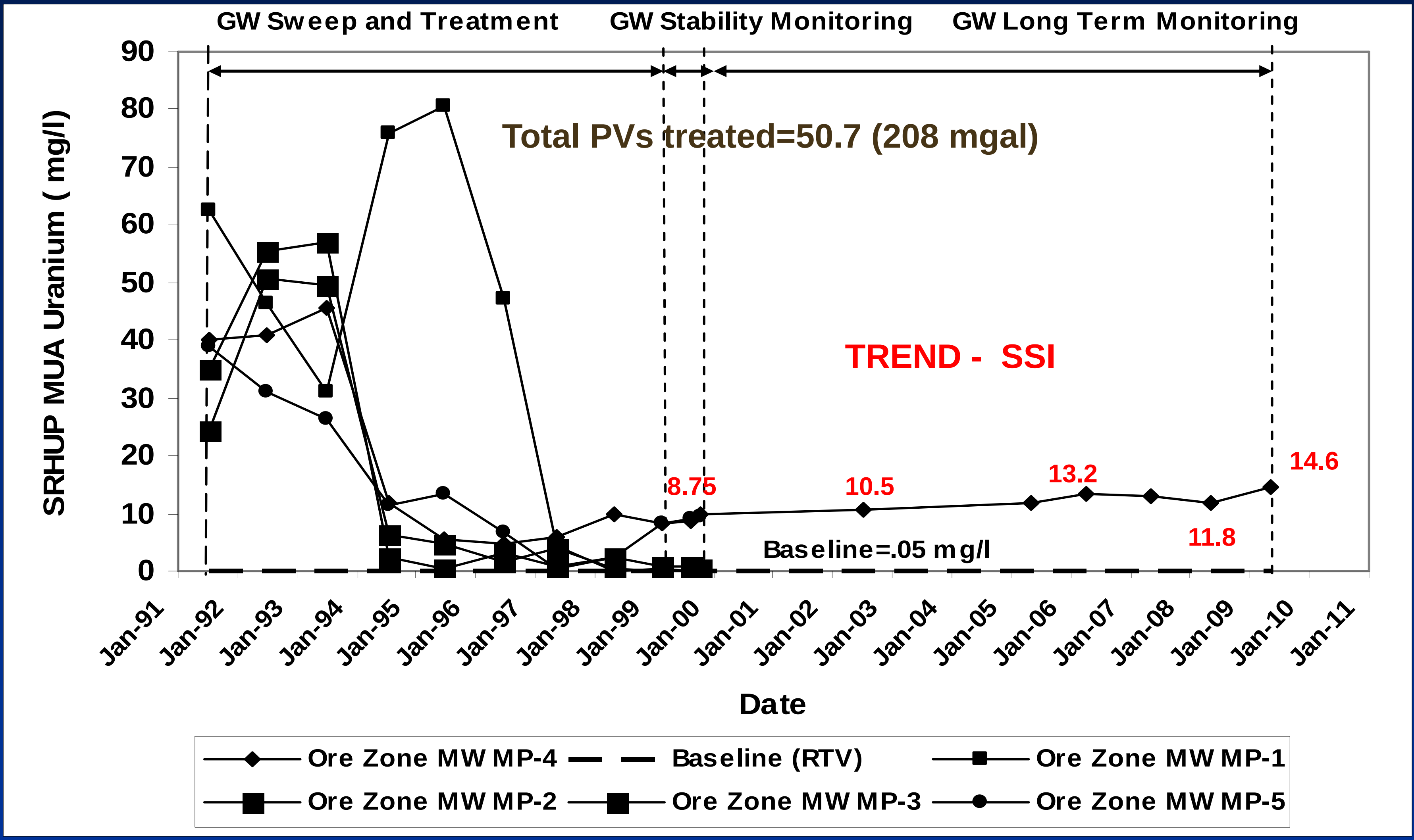
ISR Restoration: Stability and Long Term Monitoring Trend Analysis



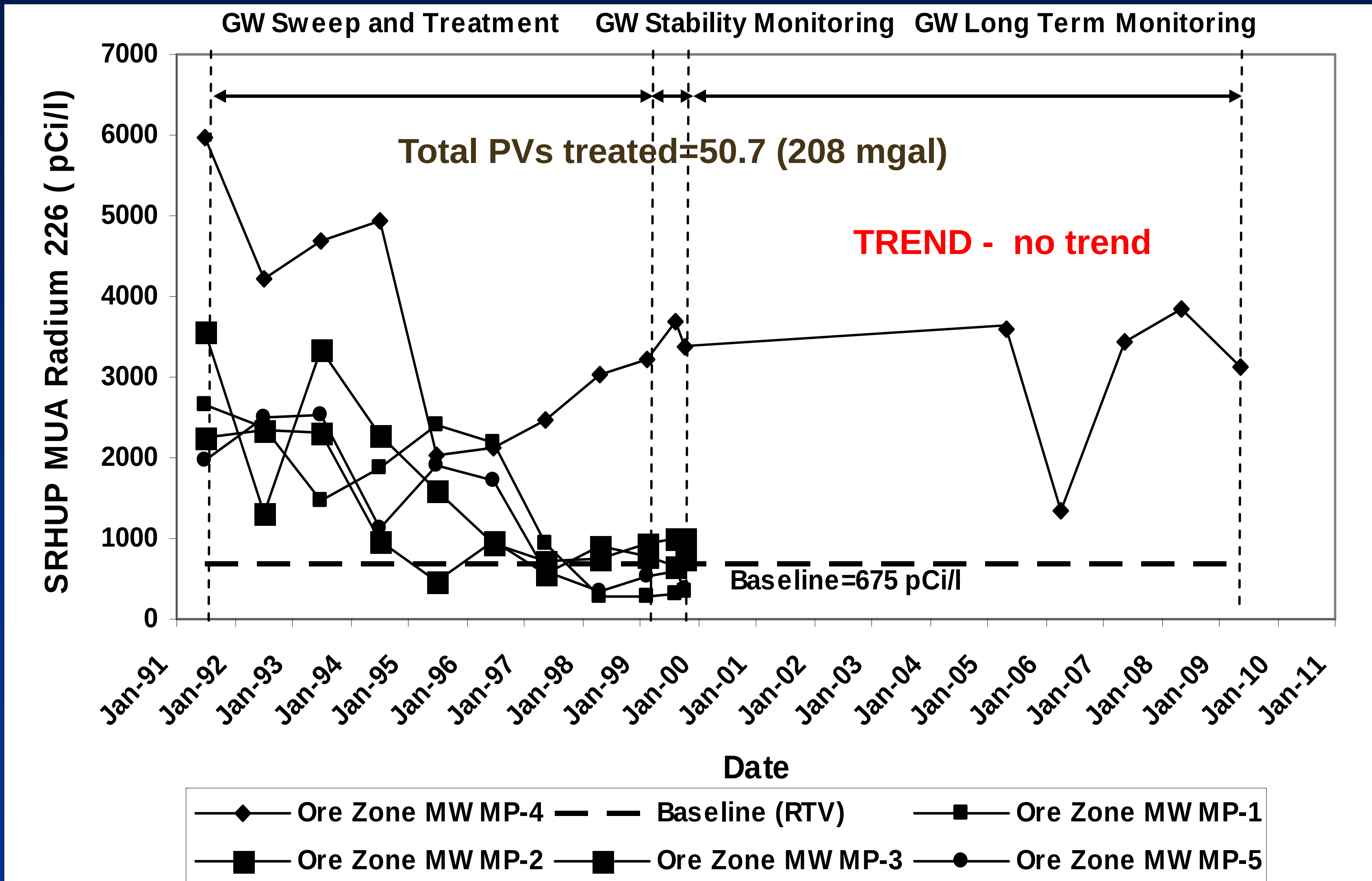
ISR Restoration: Stability and Long Term Monitoring Trend Analysis



ISR Restoration: Stability and Long Term Monitoring Trend Analysis



ISR Restoration: Stability and Long Term Monitoring Trend Analysis



Lessons Learned: ISR Hydrogeology Emerging Issues

- **Evaluation of consumptive water use**
- **Evaluation of interaction with nearby ISR operations**
- **New lixiviants (different chemistry to avoid oxidation and mobilization of metals)**
- **ACLs – requires license amendment and review under Criterion 5B(6) (requires several hazard /risk assessments and long term monitoring of "point of exposure" wells)**
- **Geochemical modeling (provides lines of evidence to support ACLs)**
- **Restoration by natural attenuation (monitor numerous parameters in perpetuity to show natural processes and reducing environments prevents contamination of USDW)**

Hydrogeology Lessons Learned: Conclusions

- Site Characterization
  - Geology
  - Existing Private Wells and CBM/oil/gas/injection wells
  - Aquifers /Aquitards
  - Aquifer Tests
  - Pre-op Water Quality
- Operations
  - Thin or discontinuous aquitards
  - Inward gradient (unconfined or confined aquifer)
  - Extraction rate limitations (unconfined or confined aquifer)
  - Monitoring well locations and excursion detection and correction
  - Free gas evolution / two phase flow / "gas lock"
  - Wellfield Hydrologic Test Data Packages
  - Analytical and Numerical Modeling
- Restoration
  - Baseline Water Quality/Restoration Standards
  - Pore Volumes/Flare
  - Wellfield sweep in unconfined aquifer
  - Waste water disposal capacity
  - Long term excursion restoration
  - Stability Monitoring Trend Analysis
- Emerging Issues
  - Consumptive water use
  - Interaction with near ISR operations
  - New lixiviants
  - ACLs
  - Geochemical Modeling
  - Natural Attenuation

Resources

- William Walton, “Groundwater Pumping Tests: Design and Analysis”
- Michael Kasenow, “ Aquifer Test Data: Analysis and Evaluation”
- EPA-530-R-09-007, "Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities: Unified Guidance,” March 2009

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Description of Restoration Phases and Stability Monitoring for NRC Approved Restorations

Table 1. Restoration Phase and Stability Sampling Summary for Irigaray MUs 1-9

ISR	Wellfields	One PV	Ground Water Sweep Period	Ground Water Sweep PVs	Ground Water Treatment Period	Ground Water Treatment PVs	Recirculation Period	Recirculation PVs	Total Restoration PVs	Stabilization Period	Stability Samples
Cogema Irigaray	Units 1-3	11.7 mg	May 1990-Apr. 1991	4.2	Apr. 1991-Nov. 1992	13.2	Oct.-Nov. 1992	1.000	18.4	Nov. 1992-Sept. 1993	4
Cogema Irigaray	Units 4-5	10.5 mg	June 1991 -Aug. 1993; April 1995-Oct.1995	3.0 ; 0.4	Oct. 1995 -Aug. 1998	9.5	Aug.-Sept. 1998	1.000	13.9	Sept. 1998-June 1999	4
Cogema Irigaray	Unit 6	13 mg	Jan. 1996-August 1998	1.4	July 2000-Oct. 2001	7.1	Oct.-Nov 2001	1.000	9.5	Nov. 2001-Aug. 2002	4
Cogema Irigaray	Unit 7	13.3 mg	Apr. 1995-Sept. 1997	1.6	Feb. 2000-July 2001	11.7	July-Aug. 2001	1.000	14.3	Aug. 2001-June 2002	4
Cogema Irigaray	Unit 8	4.5 mg	Apr. 1995-Sept. 1997	1.4	March 1999-June 2001	10.2	Jul-Aug. 2000	0.900	12.5	Aug. 2000-June 2001	4
Cogema Irigaray	Unit 9	9.4 mg	Apr. 1995-Sept. 1997	1.7	Nov. 1998-Apr. 2000	10.7	Apr.-May 2000	0.500	13	May 2000-Jan. 2001	4

Table 2. Restoration Phase and Stability Sampling Summary for Crow Butte Resources MU 1

ISR	Well field	One PV	Ground Water Transfer/ Sweep Period	Ground Water Sweep PVs	Ground Water Treatment Period	Ground Water Treatment PVs	Reductant/ Recirculation Period	Reductant/ Recirculation PVs	Total Restoration PVs	Stabilization Period	Stability Samples	Confirmatory Sampling Period	Confirmatory Samples
CBR	MU1	17.2mg	Apr. 1994-July 1997	1.08	Oct. 1995-July 1998	6.02	Aug. 1998 - Feb. 1999	2.85	9.95	Feb. 1999-Aug. 1999	6	July 2002-Sept. 2002	4

Table 3. Restoration Phase and Stability Sampling Summary for Smith Ranch Highlands Uranium Project MU A

ISR	Well Field	One PV	Ground Water Sweep Period	Ground Water Sweep PVs	Ground Water Treatment Period	Ground Water Treatment PVs	Ground Water Recirculation Period	Ground Water Recirculation PVs	Total Rest. PVs	Stabilization Period	Stability Samples	Long Term Monitoring Period	Long Term Samples
SR-HUP	MUA	4.1 mg	July 1991 - June 1994	3.2	June 1994 -Nov. 1997	30	June 1994 -Nov. 1997	5	50.7	Feb. 1999-Oct. 1999	3	July 2002-May 2009	6